

ZIGBEE SPECIFICATION

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Abstract	The ZigBee Specification describes the infrastructure and services available to applications operating on the ZigBee platform.
Keywords	ZigBee, Stack, Network, Application, Profile, Framework, Device Description, Binding, Security

September 19, 2012

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DOCUMENT HISTORY

ZigBee Specification History

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r06	February 17, 2006	ZigBee Specification (ZigBee document number 053474r06/07) incorporating errata and clarifications: ZigBee document numbers 053920r02, 053954r02, 06084r00, and 053474r07
r07	April 28, 2006	Changes made per Editorial comments on spreadsheet,
r13	October 9, 2006	ZigBee-2006 Specification (see letter ballot comments and resolution in ZigBee document 064112)
r14	November 3, 2006	ZigBee-2007 Specification (adds features described in 064270, 064269, 064268, 064281, 064319, and 064293)
r15	December 12, 2006	ZigBee-2007 Specification incorporating errata and clarifications: 074746
r16	May 31, 2007	ZigBee-2007 Specification incorporating errata and clarifications: 07819
r17	October 19, 2007	ZigBee-2007 specification incorporating errata: 075318, 075053, 075164, 075098
r18	June 16, 2009	ZigBee-2007 specification incorporating errata: 08012
r19	September 28, 2010	ZigBee-2007 specification incorporating errata described in document 105413r04
r20	September 18, 2012	ZigBee-2007 specification incorporating errata described in 11-53778-r13 and 12-0030-01

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TABLE OF CONTENTS

	1
	2
	3
	4
Notice of Use and Disclosure	i
	5
Document History	iii
	6
List of Tables	xi
	7
List of Figures	xix
	8
	9
Chapter 1 ZigBee Protocol Overview	1
	10
1.1 Protocol Description	1
	11
1.1.1 Scope	1
	12
1.1.2 Purpose.	1
	13
1.1.3 Stack Architecture	1
	14
1.1.4 Network Topology	3
	15
1.2 Conventions and Abbreviations	3
	16
1.2.1 Conventions	3
	17
1.3 Acronyms and Abbreviations	4
	18
1.4 Glossary	6
	19
1.4.1 Definitions	6
	20
1.5 References.	14
	21
1.5.1 ZigBee/IEEE References	14
	22
1.5.2 Normative References	14
	23
1.5.3 Informative References	15
	24
Chapter 2 Application Layer Specification	17
	25
2.1 General Description	17
	26
2.1.1 Application Support Sub-Layer	17
	27
2.1.2 Application Framework	18
	28
2.1.3 ZigBee Device Objects	18
	29
2.2 ZigBee Application Support (APS) Sub-Layer	19
	30
2.2.1 Scope	19
	31
2.2.2 Purpose.	19
	32
2.2.3 Application Support (APS) Sub-Layer Overview	20
	33
2.2.4 Service Specification	21
	34
2.2.5 Frame Formats	51
	35
2.2.6 Command Frames	59
	36
2.2.7 Constants and PIB Attributes.	60
	37
2.2.8 Functional Description.	63
	38
	39
	40
	41
	42
	43
	44
	45

2.2.9 APS Sub-Layer Status Values	75	
2.3 The ZigBee Application Framework	77	1
2.3.1 Creating a ZigBee Profile	77	2
2.3.2 ZigBee Descriptors	80	3
2.3.3 Functional Description	93	4
2.4 The ZigBee Device Profile	94	5
2.4.1 Scope	94	6
2.4.2 Device Profile Overview	94	7
2.4.3 Client Services	99	8
2.4.4 Server Services	152	9
2.4.5 ZDP Enumeration Description	214	10
2.4.6 Conformance	215	11
2.5 The ZigBee Device Objects (ZDO)	215	12
2.5.1 Scope	215	13
2.5.2 Device Object Descriptions	216	14
2.5.3 Layer Interface Description	223	15
2.5.4 System Usage	224	16
2.5.5 Object Definition and Behavior	227	17
2.5.6 Configuration Attributes	255	18
Chapter 3 Network Specification	261	19
3.1 General Description	261	20
3.1.1 Network (NWK) Layer Overview	261	21
3.2 Service Specification	262	22
3.2.1 NWK Data Service	263	23
3.2.2 NWK Management Service	270	24
3.3 Frame Formats	309	25
3.3.1 General NPDU Frame Format	309	26
3.3.2 Format of Individual Frame Types	314	27
3.4 Command Frames	316	28
3.4.1 Route Request Command	317	29
3.4.2 Route Reply Command	319	30
3.4.3 Network Status Command	322	31
3.4.4 Leave Command	326	32
3.4.5 Route Record Command	328	33
3.4.6 Rejoin Request Command	330	34
3.4.7 Rejoin Response Command	331	35
3.4.8 Link Status Command	333	36
3.4.9 Network Report Command	335	37
		38
		39
		40
		41
		42
		43
		44
		45

3.4.10 Network Update Command	338	
3.5 Constants and NIB Attributes	341	1
3.5.1 NWK Constants	341	2
3.5.2 NWK Information Base	342	3
3.6 Functional Description	350	4
3.6.1 Network and Device Maintenance	350	5
3.6.2 Transmission and Reception	385	6
3.6.3 Routing	388	7
3.6.4 Scheduling Beacon Transmissions	409	8
3.6.5 Broadcast Communication	411	9
3.6.6 Multicast Communication	415	10
3.6.7 NWK Information in the MAC Beacons	419	11
3.6.8 Persistent Data	421	12
3.6.9 Low Power Routers (LPR)	421	13
3.7 NWK Layer Status Values	421	14
Chapter 4 Security Services Specification	425	15
4.1 Document Organization	425	16
4.2 General Description	425	17
4.2.1 Security Architecture and Design	426	18
4.2.2 NWK Layer Security	429	19
4.2.3 APL Layer Security	430	20
4.2.4 Trust Center Role	432	21
4.3 NWK Layer Security	433	22
4.3.1 Frame Security	433	23
4.3.2 Secured NPDU Frame	436	24
4.3.3 Security-Related NIB Attributes	437	25
4.4 APS Layer Security	440	26
4.4.1 Frame Security	441	27
4.4.2 Key-Establishment Services	448	28
4.4.3 Transport-Key Services	459	29
4.4.4 Update Device Services	467	30
4.4.5 Remove Device Services	471	31
4.4.6 Request Key Services	473	32
4.4.7 Switch Key Services	476	33
4.4.8 Entity Authentication Services	478	34
4.4.9 Command Frames	485	35
4.4.10 Security-Related AIB Attributes	497	36
4.5 Common Security Elements	498	37
		38
		39
		40
		41
		42
		43
		44
		45

4.5.1 Auxiliary Frame Header Format	499	1
4.5.2 Security Parameters	501	2
4.5.3 Cryptographic Key Hierarchy	502	3
4.5.4 Implementation Guidelines (Informative)	502	4
4.6 Functional Description	503	5
4.6.1 ZigBee Coordinator	503	6
4.6.2 Trust Center Application	503	7
4.6.3 Security Procedures	504	8
Annex A CCM* Mode of Operation	531	9
A.1 Notation and Representation	532	10
A.2 CCM* Mode Encryption and Authentication Transformation . . .	532	11
A.2.1 Input Transformation	533	12
A.2.2 Authentication Transformation	533	13
A.2.3 Encryption Transformation	534	14
A.3 CCM* Mode Decryption and Authentication		15
Checking Transformation	535	16
A.3.1 Decryption Transformation	535	17
A.3.2 Authentication Checking Transformation	536	18
A.4 Restrictions	536	19
Annex B Security Building Blocks	537	20
B.1 Symmetric-Key Cryptographic Building Blocks	537	21
B.1.1 Block-Cipher	537	22
B.1.2 Mode of Operation	537	23
B.1.3 Cryptographic Hash Function	538	24
B.1.4 Keyed Hash Function for Message Authentication	538	25
B.1.5 Specialized Keyed Hash Function for		26
Message Authentication	538	27
B.1.6 Challenge Domain Parameters	538	28
B.2 Key Agreement Schemes	539	29
B.2.1 Symmetric-Key Key Agreement Scheme	539	30
B.3 Challenge Domain Parameter Generation and Validation	539	31
B.3.1 Challenge Domain Parameter Generation	540	32
B.3.2 Challenge Domain Parameter Verification	540	33
B.4 Challenge Validation Primitive	540	34
B.5 Secret Key Generation (SKG) Primitive	541	35
B.6 Block-Cipher-Based Cryptographic Hash Function	542	36
B.7 Symmetric-Key Authenticated Key Agreement Scheme	543	37
B.7.1 Initiator Transformation	545	38
		39
		40
		41
		42
		43
		44
		45

B.7.2 Responder Transformation	546	
B.8 Mutual Symmetric-Key Entity Authentication	548	1
B.8.1 Initiator Transformation	550	2
B.8.2 Responder Transformation	551	3
Annex C Test Vectors For Cryptographic Building Blocks	553	4
C.1 Data Conversions	553	5
C.2 AES Block Cipher	553	6
C.3 CCM* Mode Encryption and Authentication Transformation . . .	553	7
C.3.1 Input Transformation	554	8
C.3.2 Authentication Transformation	555	9
C.3.3 Encryption Transformation	555	10
C.4 CCM* Mode Decryption and Authentication		11
Checking Transformation	557	12
C.4.1 Decryption Transformation	557	13
C.4.2 Authentication Checking Transformation	558	14
C.5 Cryptographic Hash Function	559	15
C.5.1 Test Vector Set 1	559	16
C.5.2 Test Vector Set 2	560	17
C.5.3 Test Vector Set 3	561	18
C.5.4 Test Vector 4	561	19
C.5.5 Test Vector 5	562	20
C.5.6 Test Vector 6	563	21
C.6 Keyed Hash Function for Message Authentication	564	22
C.6.1 Test Vector Set 1	564	23
C.6.2 Test Vector Set 2	566	24
C.6.3 Specialized Keyed Hash Function for Message		25
Authentication	567	26
C.6.4 Symmetric-Key Key Agreement Scheme and Entity		27
Authentication Scheme	567	28
Annex D MAC and PHY Sub-Layer Clarifications	581	29
D.1 Introduction	581	30
D.1.1 Scope	581	31
D.1.2 Purpose	581	32
D.2 Stack Size Issues	581	33
D.3 MAC Association	582	34
D.4 aMaxMACFrameSize	583	35
D.5 Beacon Timing	584	36
D.6 CSMA Backoff Timing	585	37
		38
		39
		40
		41
		42
		43
		44
		45

Annex E Operation of Network Manager as Network Channel	
Manager for Interference Reporting and Resolution	587
Annex F Usage of Multiple Frequency Bands	591
F.1 Introduction	591
F.1.1 Scope	591
F.1.2 Purpose	591
F.2 Channels and Channel Masks Management General Guideline. . .	592
F.2.1 Channel Selection During Network Establishment.	592
F.2.2 The Frequency Agility Feature Related Points	592
F.2.3 Network Management Services and Client Services	
Affected by Multiple Frequency Bands Support	592
F.3 Timing Issues	593

LIST OF TABLES

	1
	2
	3
	4
Table 1.1 ZigBee Protocol Versions	7
Table 2.1 APSDE-SAP Primitives	22
Table 2.2 APSDE-DATA.request Parameters	24
Table 2.3 APSDE-DATA.confirm Parameters	28
Table 2.4 APSDE-DATA.indication Parameters	30
Table 2.5 Summary of the Primitives Accessed Through the APSME-SAP	33
Table 2.6 APSME-BIND.request Parameters	34
Table 2.7 APSME-BIND.confirm Parameters	36
Table 2.8 APSME-UNBIND.request Parameters	38
Table 2.9 APSME-UNBIND.confirm Parameters	40
Table 2.10 APSME-GET.request Parameters	41
Table 2.11 APSME-GET.confirm Parameters	42
Table 2.12 APSME-SET.request Parameters	43
Table 2.13 APSME-SET.confirm Parameters	44
Table 2.14 APSME-ADD-GROUP.request Parameters	45
Table 2.15 APSME-ADD-GROUP.confirm Parameters	46
Table 2.16 APSME-REMOVE-GROUP.request Parameters	47
Table 2.17 APSME-REMOVE-GROUP.confirm Parameters	48
Table 2.18 APSME-REMOVE-ALL-GROUPS.request Parameters	49
Table 2.19 APSME-REMOVE-ALL-GROUPS.confirm Parameters	50
Table 2.20 Values of the Frame Type Sub-Field	52
Table 2.21 Values of the Delivery Mode Sub-Field	53
Table 2.22 Values of the Fragmentation Sub-Field	56
Table 2.23 APS Sub-Layer Constants	60
Table 2.24 APS IB Attributes	61
Table 2.25 Group Table Entry Format	62
Table 2.26 apsMaxWindowSize by Endpoint Number	63
Table 2.27 APS Sub-layer Status Values	75
Table 2.28 ZigBee Descriptors	80
Table 2.29 Fields of the Node Descriptor	82
Table 2.30 Values of the Logical Type Field	83

Table 2.31	Values of the Frequency Band Field	84	
Table 2.32	Server Mask Bit Assignments	85	1
Table 2.33	Descriptor Capability Bit Assignments	86	2
Table 2.34	Fields of the Node Power Descriptor	86	3
Table 2.35	Values of the Current Power Mode Field	87	4
Table 2.36	Values of the Available Power Sources Field	87	5
Table 2.37	Values of the Current Power Sources Field	88	6
Table 2.38	Values of the Current Power Source Level Field	88	7
Table 2.39	Fields of the Simple Descriptor	89	8
Table 2.40	Values of the Application Device Version Field	90	9
Table 2.41	Fields of the Complex Descriptor	91	10
Table 2.42	Values of the Character Set Identifier Sub-Field	92	11
Table 2.43	Fields of the User Descriptor	93	12
Table 2.44	Device and Service Discovery Client Services		13
	Commands	99	14
Table 2.45	Fields of the NWK_addr_req Command	101	15
Table 2.46	Fields of the IEEE_addr_req Command	102	16
Table 2.47	Fields of the Node_Desc_req Command	104	17
Table 2.48	Fields of the Power_Desc_req Command	105	18
Table 2.49	Fields of the Simple_Desc_req Command	105	19
Table 2.50	Fields of the Active_EP_req Command	106	20
Table 2.51	Fields of the Match_Desc_req Command	107	21
Table 2.52	Fields of the Complex_Desc_req Command	109	22
Table 2.53	Fields of the User_Desc_req Command	109	23
Table 2.54	Fields of the Discovery_Cache_req Command	110	24
Table 2.55	Fields of the Device_annce Command	111	25
Table 2.56	Fields of the User_Desc_set Command	112	26
Table 2.57	Fields of the System_Server_Discovery_req Command ..	113	27
Table 2.58	Fields of the Discovery_store_req Command	114	28
Table 2.59	Fields of the Node_Desc_store_req Command	115	29
Table 2.60	Fields of the Power_Desc_store_req Command	116	30
Table 2.61	Fields of the Active_EP_store_req Command	117	31
Table 2.62	Fields of the Simple_Desc_store_req Command	119	32
Table 2.63	Fields of the Remove_node_cache_req Command	120	33
Table 2.64	Fields of the Find_node_cache_req Command Frame ..	121	34
Table 2.65	Fields of the Extended_Simple_Desc_req Command ...	122	35
Table 2.66	Fields of the Extended_Active_EP_req Command	123	36
			37
			38
			39
			40
			41
			42
			43
			44
			45

Table 2.67	End Device Bind, Bind, Unbind, and Bind Management Client Service Commands	124	1
Table 2.68	Fields of the End_Device_Bind_req Command	125	2
Table 2.69	Fields of the Bind_req Command	127	3
Table 2.70	Fields of the Unbind_req Command	129	4
Table 2.71	Fields of the Bind_Register_req Command	130	5
Table 2.72	Fields of the Replace_Device_req Command	131	6
Table 2.73	Fields of the Store_Bkup_Bind_Entry_req Command	133	7
Table 2.74	Fields of the Remove_Bkup_Bind_Entry_req Command	134	8
Table 2.75	Fields of the Backup_Bind_Table_req Command	136	9
Table 2.76	Fields of the Recover_Bind_Table_req Command	137	10
Table 2.77	Fields of the Backup_Source_Bind_req Command	138	11
Table 2.78	Fields of the Recover_Source_Bind_req Command	139	12
Table 2.79	Network Management Client Services Commands	140	13
Table 2.80	Fields of the Mgmt_NWK_Disc_req Command	141	14
Table 2.81	Fields of the Mgmt_Lqi_req Command	142	15
Table 2.82	Fields of the Mgmt_Rtg_req Command	143	16
Table 2.83	Fields of the Mgmt_Bind_req Command	144	17
Table 2.84	Fields of the Mgmt_Leave_req Command	145	18
Table 2.85	Fields of the Mgmt_Direct_Join_req Command	146	19
Table 2.86	Fields of the Mgmt_Permit_Joining_req Command	147	20
Table 2.87	Fields of the Mgmt_Cache_req Command	149	21
Table 2.88	Fields of the Mgmt_NWK_Update_req Command	150	22
Table 2.89	Device and Service Discovery Server Service Primitives	153	23
Table 2.90	Fields of the NWK_addr_rsp Command	154	24
Table 2.91	IEEE_addr_rsp Parameters	156	25
Table 2.92	Fields of the Node_Desc_rsp Command	158	26
Table 2.93	Fields of the Power_Desc_rsp Command	160	27
Table 2.94	Fields of the Simple_Desc_rsp Command	161	28
Table 2.95	Fields of the Active_EP_rsp Command	163	29
Table 2.96	Fields of the Match_Desc_rsp Command	165	30
Table 2.97	Fields of the Complex_Desc_rsp Command	167	31
Table 2.98	Fields of the User_Desc_rsp Command	169	32
Table 2.99	Fields of the System_Server_Discovery_rsp Command	171	33
Table 2.100	Fields of the User_Desc_conf Command	172	34

Table 2.101	Fields of the Discovery_Cache_rsp Command	173	
Table 2.102	Fields of the Discovery_store_rsp Command	174	1
Table 2.103	Fields of the Node_Desc_store_rsp Command	175	2
Table 2.104	Fields of the Power_Desc_store_rsp Command	176	3
Table 2.105	Fields of the Active_EP_store_rsp Command	177	4
Table 2.106	Fields of the Simple_Desc_store_rsp Command	178	5
Table 2.107	Fields of the Remove_node_cache_rsp Command	179	6
Table 2.108	Fields of the Find_node_cache_rsp Command	180	7
Table 2.109	Fields of the Extended_Simple_Desc_rsp Command	181	8
Table 2.110	Fields of the Extended_Active_EP_rsp Command	183	9
Table 2.111	End Device Bind, Unbind and Bind Management		10
	Server Services Primitives	185	11
Table 2.112	Fields of the End_Device_Bind_rsp Command	186	12
Table 2.113	Fields of the Bind_rsp Command	187	13
Table 2.114	Fields of the Unbind_rsp Command	188	14
Table 2.115	Fields of the Bind_Register_rsp Command	189	15
Table 2.116	Fields of the Replace_Device_rsp Command	190	16
Table 2.117	Fields of the Store_Bkup_Bind_Entry_rsp Command	191	17
Table 2.118	Fields of the Remove_Bkup_Bind_Entry_rsp Command	192	18
Table 2.119	Fields of the Backup_Bind_Table_rsp Command	193	19
Table 2.120	Fields of the Recover_Bind_Table_rsp Command	194	20
Table 2.121	Fields of the Backup_Source_Bind_rsp Command	195	21
Table 2.122	Fields of the Recover_Source_Bind_rsp Command	196	22
Table 2.123	Network Management Server Service Commands	197	23
Table 2.124	Fields of the Mgmt_NWK_Disc_rsp Command	197	24
Table 2.125	NetworkList Record Format	198	25
Table 2.126	Fields of the Mgmt_Lqi_rsp Command	200	26
Table 2.127	NeighborTableList Record Format	201	27
Table 2.128	Fields of the Mgmt_Rtg_rsp Command	203	28
Table 2.129	RoutingTableList Record Format	204	29
Table 2.130	Fields of the Mgmt_Bind_rsp Command	205	30
Table 2.131	BindingTableList Record Format	206	31
Table 2.132	Fields of the Mgmt_Leave_rsp Command	208	32
Table 2.133	Fields of the Mgmt_Direct_Join_rsp Command	209	33
Table 2.134	Fields of the Mgmt_Permit_Joining_rsp Command	210	34
Table 2.135	Fields of the Mgmt_Cache_rsp Command	211	35
Table 2.136	DiscoveryCacheList Record Format	211	36
			37
			38
			39
			40
			41
			42
			43
			44
			45

Table 2.137	Fields of the Mgmt_NWK_Update_notify Command ..	213	
Table 2.138	ZDP Enumerations Description	214	1
Table 2.139	ZigBee Device Objects	228	2
Table 2.140	Startup Attributes	244	3
Table 2.141	Additional Commissioning Attributes	245	4
Table 2.142	Device and Service Discovery Attributes	246	5
Table 2.143	Security Manager Attributes	248	6
Table 2.144	Binding Manager Attributes	249	7
Table 2.145	Network Manager Attributes	252	8
Table 2.146	Node Manager Attributes	253	9
Table 2.147	Group Manager Attributes	254	10
Table 2.148	Configuration Attributes	255	11
Table 2.149	Configuration Attribute Definitions	256	12
Table 3.1	NLDE-SAP Primitives	263	13
Table 3.2	NLDE-DATA.request Parameters	264	14
Table 3.3	NLDE-DATA.confirm Parameters	267	15
Table 3.4	NLDE-DATA.indication Parameters	268	16
Table 3.5	Summary of the Primitives Accessed Through the NLME-SAP	270	17
Table 3.6	NLME-NETWORK-DISCOVERY.request Parameters ..	271	18
Table 3.7	NLME-NETWORK-DISCOVERY.confirm Parameters ..	272	19
Table 3.8	Network Descriptor Information Fields	272	20
Table 3.9	NLME-NETWORK-FORMATION.request Parameters ..	274	21
Table 3.10	NLME-NETWORK-FORMATION.confirm Parameters	276	22
Table 3.11	NLME-PERMIT-JOINING.request Parameters	277	23
Table 3.12	NLME-PERMIT-JOINING.confirm Parameters	278	24
Table 3.13	NLME-START-ROUTER.request Parameters	279	25
Table 3.14	NLME-START-ROUTER.confirm Parameters	280	26
Table 3.15	NLME-ED-SCAN.request Parameters	281	27
Table 3.16	NLME-ED-SCAN.confirm	282	28
Table 3.17	NLME-JOIN.request Parameters	283	29
Table 3.18	NLME-JOIN.indication Parameters	286	30
Table 3.19	NLME-JOIN.confirm Parameters	287	31
Table 3.20	NLME-DIRECT-JOIN.request Parameters	288	32
Table 3.21	NLME-DIRECT-JOIN.confirm Parameters	289	33
Table 3.22	NLME-LEAVE.request Parameters	290	34
Table 3.23	NLME-LEAVE.indication Parameters	292	35

Table 3.24	NLME-LEAVE.confirm Parameters	293	
Table 3.25	NLME-RESET.request Parameters	294	1
Table 3.26	NLME-RESET.confirm Parameters	295	2
Table 3.27	NLME-SYNC.request Parameters	297	3
Table 3.28	NLME-SYNC.confirm Parameters	298	4
Table 3.29	NLME-GET.request Parameters	300	5
Table 3.30	NLME-GET.confirm Parameters	301	6
Table 3.31	NLME-SET.request Parameters	302	7
Table 3.32	NLME-SET.confirm Parameters	303	8
Table 3.33	NLME-NWK-STATUS.indication Parameters	304	9
Table 3.34	NLME-ROUTE-DISCOVERY.request Parameters	306	10
Table 3.35	NLME_ROUTE-DISCOVERY.confirm Parameters	308	11
Table 3.36	Allowable Frame Control Sub-Field Configurations	310	12
Table 3.37	Values of the Frame Type Sub-Field	310	13
Table 3.38	Values of the Discover Route Sub-Field	311	14
Table 3.39	Values of the Multicast Mode Sub-Field	313	15
Table 3.40	NWK Command Frames	316	16
Table 3.41	Many-to-One Field Values	318	17
Table 3.42	Status Codes for Network Status Command Frame	324	18
Table 3.43	NWK Layer Constants	341	19
Table 3.44	NIB Attributes	343	20
Table 3.45	Route Record Table Entry Format	350	21
Table 3.46	Network Address Map	350	22
Table 3.47	Capability Information Bit-Fields	356	23
Table 3.48	Neighbor Table Entry Format	370	24
Table 3.49	Additional Neighbor Table Fields	372	25
Table 3.50	Example Addressing Offset Values for Each Given Depth Within the Network	374	26
Table 3.51	Routing Table Entry	390	27
Table 3.52	Route Status Values	390	28
Table 3.53	Route Discovery Table Entry	391	29
Table 3.54	Broadcast Addresses	412	30
Table 3.55	Broadcast Transaction Record	413	31
Table 3.56	NWK Layer Information Fields	419	32
Table 3.57	NWK Layer Status Values	422	33
Table 4.1	NIB Security Attributes	437	34
Table 4.2	Elements of the Network Security Material Descriptor	439	35
Table 4.3	Elements of the Incoming Frame Counter Descriptor	439	36
			37
			38
			39
			40
			41
			42
			43
			44
			45

Table 4.4	The APS Layer Security Primitives	440	
Table 4.5	Security Policy for Accepting APS Commands	446	1
Table 4.6	Security Policy for Sending APS Commands	447	2
Table 4.7	APSME-ESTABLISH-KEY.request Parameters	449	3
Table 4.8	APSME-ESTABLISH-KEY.confirm Parameters	451	4
Table 4.9	APSME-ESTABLISH-KEY.indication Parameters	452	5
Table 4.10	APSME-ESTABLISH-KEY.response Parameters	453	6
Table 4.11	Mapping of Frame Names to Symmetric-Key Key Agreement Scheme Messages	455	7
Table 4.12	Mapping of Symmetric-Key Key Agreement Error Conditions to Status Codes	456	8
Table 4.13	APSME-TRANSPORT-KEY.request Parameters	460	9
Table 4.14	KeyType Parameter of the Transport-Key Primitive	460	10
Table 4.15	TransportKeyData Parameter for a Trust Center Master Key or Link Key	461	11
Table 4.16	TransportKeyData Parameter for a Network Key	461	12
Table 4.17	TransportKeyData Parameter for an Application Master or Link Key	462	13
Table 4.18	APSME-TRANSPORT-KEY.indication Parameters	464	14
Table 4.19	TransportKeyData Parameter for a Trust Center Master or Link Key	465	15
Table 4.20	TransportKeyData Parameter for a Network Key	465	16
Table 4.21	TransportKeyData Parameter for an Application Master or Link Key	465	17
Table 4.22	APSME-UPDATE-DEVICE.request Parameters	468	18
Table 4.23	APSME-UPDATE-DEVICE.indication Parameters	470	19
Table 4.24	APSME-REMOVE-DEVICE.request Parameters	471	20
Table 4.25	APSME-REMOVE-DEVICE.indication Parameters	472	21
Table 4.26	APSME-REQUEST-KEY.request Parameters	474	22
Table 4.27	APSME-REQUEST-KEY.indication Parameters	475	23
Table 4.28	APSME-SWITCH-KEY.request Parameters	476	24
Table 4.29	APSME-SWITCH-KEY.indication Parameters	477	25
Table 4.30	APSME-AUTHENTICATE.request Parameter	479	26
Table 4.31	Action Parameter Enumeration	479	27
Table 4.32	APSME-AUTHENTICATE.confirm Parameters	480	28
Table 4.33	APSME-AUTHENTICATE.indication Parameters	481	29
Table 4.34	Mapping of Frame Names to Mutual Entity Authentication Scheme Messages	484	30
			31
			32
			33
			34
			35
			36
			37
			38
			39
			40
			41
			42
			43
			44
			45

Table 4.35	Mapping of Mutual Entity Authentication Error	
	Conditions to Status Codes	484
Table 4.36	Command Identifier Values	485
Table 4.37	Values of the KeyType Sub-Field	493
Table 4.38	AIB Security Attributes	497
Table 4.39	Elements of the Key-Pair Descriptor	498
Table 4.40	Security Levels Available to the NWK, and	
	APS Layers	499
Table 4.41	Encoding for the Key Identifier Sub-Field	500
Table 4.42	Mapping of NLME-JOIN.indication Parameters to	
	Update Device Status	507
Table 4.43	Elements of the Permissions Configuration Table	527
Table 4.44	Elements of the Permissions Descriptor	528
Table D.1	Associate Request Header Fields	582
Table D.2	Data Request Header Fields	583
Table D.3	Association Response Header Fields	583
Table D.4	Start Time for Beacon Transmissions	585
Table F.1	Internal Time-related Parameters	593
		1
		2
		3
		4
		5
		6
		7
		8
		9
		10
		11
		12
		13
		14
		15
		16
		17
		18
		19
		20
		21
		22
		23
		24
		25
		26
		27
		28
		29
		30
		31
		32
		33
		34
		35
		36
		37
		38
		39
		40
		41
		42
		43
		44
		45

LIST OF FIGURES

Figure 1.1	Outline of the ZigBee Stack Architecture	2
Figure 2.1	The APS Sub-Layer Reference Model	22
Figure 2.2	General APS Frame Format	52
Figure 2.3	Format of the Frame Control Field	52
Figure 2.4	Format of the Extended Header Sub-Frame	55
Figure 2.5	Format of the Extended Frame Control Field	55
Figure 2.6	Data Frame Format	57
Figure 2.7	APS Command Frame Format	58
Figure 2.8	Acknowledgement Frame Format	58
Figure 2.9	Binding on a Device Supporting a Binding Table	65
Figure 2.10	Successful Data Transmission Without an Acknowledgement	68
Figure 2.11	Successful Data Transmission With an Acknowledgement	69
Figure 2.12	Successful Data Transmission with Fragmentation	73
Figure 2.13	Fragmented Data Transmission with a Single Retransmission	74
Figure 2.14	Fragmented Data Transmission with Multiple Retransmissions	75
Figure 2.15	Format of the Complex Descriptor	81
Figure 2.16	Format of an Individual Complex Descriptor Field	81
Figure 2.17	Format of the MAC Capability Flags Field	84
Figure 2.18	Format of the Language and Character Set Field	91
Figure 2.19	Format of the ZDP Frame	98
Figure 2.20	Format of the NWK_addr_req Command	100
Figure 2.21	Format of the IEEE_addr_req Command Frame	102
Figure 2.22	Format of the Node_Desc_req Command Frame	104
Figure 2.23	Format of the Power_Desc_req Command Frame	104
Figure 2.24	Format of the Simple_Desc_req Command Frame	105
Figure 2.25	Format of the Active_EP_req Command Frame	106
Figure 2.26	Format of the Match_Desc_req Command Frame	107
Figure 2.27	Format of the Complex_Desc_req Command Frame	108
Figure 2.28	Format of the User_Desc_req Command Frame	109

Figure 2.29 Format of the Discovery_Cache_req Command	
Frame	110
Figure 2.30 Format of the Device_annce Command Frame	111
Figure 2.31 Format of the User_Desc_set Command Frame	112
Figure 2.32 Format of the System_Server_Discovery_req	
Command Frame	113
Figure 2.33 Format of the Discovery_Store_req Command Frame .	114
Figure 2.34 Format of the Node_Desc_store_req Command	
Frame	115
Figure 2.35 Format of the Power_Desc_store_req Command	
Frame	116
Figure 2.36 Format of the Active_EP_store_req Command Frame .	117
Figure 2.37 Format of the Simple_Desc_store_req Command	
Frame	118
Figure 2.38 Format of the Remove_node_cache_req Command	
Frame	120
Figure 2.39 Format of the Find_node_cache Command Frame	121
Figure 2.40 Format of the Extended_Simple_Desc_req Command	
Frame	122
Figure 2.41 Format of the Extended_Active_EP_req Command	
Frame	123
Figure 2.42 Format of the End_Device_Bind_req Command	
Frame	125
Figure 2.43 Format of the Bind_req Command Frame	127
Figure 2.44 Format of the Unbind_req Command Frame	129
Figure 2.45 Format of the Bind_Register_req Command Frame ...	130
Figure 2.46 Format of the Replace_Device_req Command Frame ..	131
Figure 2.47 Format of the Store_Bkup_Bind_Entry_req Command	
Frame	133
Figure 2.48 Format of the Remove_Bkup_Bind_Entry_req	
Command Frame	134
Figure 2.49 Format of the Backup_Bind_Table_req Command	
Frame	136
Figure 2.50 Fields of the Recover_Bind_Table_req Command	
Frame	137
Figure 2.51 Fields of the Backup_Source_Bind_req Command	
Frame	138

Figure 2.52	Format of the Recover_Source_Bind_req Command	
Frame	.....	139
Figure 2.53	Format of the Mgmt_NWK_Disc_req Command	
Frame	.....	140
Figure 2.54	Format of the Mgmt_Lqi_req Command Frame	..... 142
Figure 2.55	Format of the Mgmt_Rtg_req Command Frame	..... 143
Figure 2.56	Format of the Mgmt_Bind_req Command Frame	..... 144
Figure 2.57	Format of the Mgmt_Leave_req Command Frame	..... 145
Figure 2.58	Format of the Mgmt_Direct_Join_req Command	
Frame	.....	146
Figure 2.59	Format of the Mgmt_Permit_Joining_req Command	
Frame	.....	147
Figure 2.60	Fields of the Mgmt_Cache_req Command Frame	..... 149
Figure 2.61	Fields of the Mgmt_NWK_Update_req Command	
Frame	.....	149
Figure 2.62	Format of the NWK_addr_rsp Command Frame	..... 153
Figure 2.63	Format of the IEEE_addr_rs Command Frame	..... 156
Figure 2.64	Format of the Node_Desc_rsp Command Frame	..... 158
Figure 2.65	Format of the Power_Desc_rsp Command Frame	..... 159
Figure 2.66	Format of the Simple_Desc_rsp Command Frame	..... 161
Figure 2.67	Format of the Active_EP_rsp Command Frame	..... 163
Figure 2.68	Format of the Match_Desc_rsp Command Frame	..... 164
Figure 2.69	Format of the Complex_Desc_rsp Command Frame	... 167
Figure 2.70	Format of the User_Desc_rsp Command Frame	..... 169
Figure 2.71	System_Server_Discovery_rsp Command Frame	..... 171
Figure 2.72	Format of the User_Desc_conf Command Frame	..... 172
Figure 2.73	Format of the Discovery_Cache_rsp Command Frame	. 173
Figure 2.74	Format of the Discovery_store_rsp Command Frame	.. 174
Figure 2.75	Format of the Node_Desc_store_rsp Command Frame	. 175
Figure 2.76	Format of the Power_Desc_store_rsp Command	
Frame	.....	176
Figure 2.77	Format of the Active_EP_store_rsp Command Frame	. 177
Figure 2.78	Format of the Simple_Desc_store_rsp Command	
Frame	.....	178
Figure 2.79	Format of the Remove_node_cache_rsp Command	
Frame	.....	179
Figure 2.80	Format of the Find_node_cache_rsp Command	
Frame	.....	180

Figure 2.81 Format of the Extended_Simple_Desc_rsp Command	
Frame	181
Figure 2.82 Format of the Extended_Active_EP_rsp Command	
Frame	183
Figure 2.83 Format of the End_Device_Bind_rsp Command	
Frame	186
Figure 2.84 Format of the Bind_rsp Command Frame	187
Figure 2.85 Format of the Unbind_rsp Command Frame	188
Figure 2.86 Format of the Bind_Register_rsp Command Frame ...	189
Figure 2.87 Format of the Replace_Device_rsp Command Frame ..	190
Figure 2.88 Format of the Store_Bkup_Bind_Entry_rsp Command	
Frame	191
Figure 2.89 Format of the Remove_Bkup_Bind_Entry_rsp	
Command Frame	191
Figure 2.90 Format of the Backup_Bind_Table_rsp Command	
Frame	192
Figure 2.91 Format of the Backup_Bind_Table_rsp Command	
Frame	193
Figure 2.92 Format of the Backup_Source_Bind_rsp Command	
Frame	195
Figure 2.93 Format of the Recover_Source_Bind_rsp Command	
Frame	195
Figure 2.94 Format of the Mgmt_NWK_Disc_rsp Command	
Frame	197
Figure 2.95 Format of the Mgmt_Lqi_rsp Command Frame	200
Figure 2.96 Format of the Mgmt_Rtg_rsp Command Frame	203
Figure 2.97 Format of the Mgmt_Bind_rsp Command Frame	205
Figure 2.98 Format of the Mgmt_Leave_rsp Command Frame	208
Figure 2.99 Format of the Mgmt_Direct_Join_rsp Command	
Frame	209
Figure 2.100 Format of the Mgmt_Permit_Joining_rsp Command	
Frame	210
Figure 2.101 Format of the Mgmt_Cache_rsp Command Frame ...	211
Figure 2.102 Format of the Mgmt_NWK_Update_notify Command	
Frame	212
Figure 2.103 Primary Discovery Cache State Machine	217
Figure 2.104 System Usage ZigBee Device Object Details	224

Figure 2.105 System Usage ZigBee Device Object Details — Node Manager Object and Security Manager Object	225	1
Figure 2.106 System Usage ZigBee Device Object Details — Binding Manager Object and Network Manager Object	226	2
Figure 2.107 System Usage ZigBee Device Object Details — Group Manager Object and Configuration Attributes	227	3
Figure 2.108 Portability Message Sequence Chart: ZED Secured Rejoin	236	4
Figure 2.109 Portability Message Sequence Chart: ZED Trust Center Rejoin	237	5
Figure 2.110 Portability Message Sequence Chart: ZR Trust Center Rejoin	238	6
Figure 3.1 The NWK Layer Reference Model	263	7
Figure 3.2 Message Sequence Chart for Resetting the Network Layer	296	8
Figure 3.3 Message Sequence Chart for Synchronizing in a Non-Beaconing Network	299	9
Figure 3.4 Message Sequence Chart for Synchronizing in a Beacon-Enabled Network	300	10
Figure 3.5 General NWK Frame Format	309	11
Figure 3.6 Frame Control Field	310	12
Figure 3.7 Multicast Control Field Format	313	13
Figure 3.8 Source Route Subframe Format	314	14
Figure 3.9 Data Frame Format	315	15
Figure 3.10 NWK Command Frame Format	315	16
Figure 3.11 Route Request Command Frame Format	317	17
Figure 3.12 Route Request Command Options Field	318	18
Figure 3.13 Route Reply Command Format	320	19
Figure 3.14 Route Reply Command Options Field	321	20
Figure 3.15 Network Status Command Frame Format	323	21
Figure 3.16 Leave Command Frame Format	326	22
Figure 3.17 Leave Command Options Field	328	23
Figure 3.18 Route Record Command Format	328	24
Figure 3.19 Rejoin Request Command Frame Format	330	25
Figure 3.20 Rejoin Response Command Frame Format	331	26
Figure 3.21 Link Status Command Format	334	27
Figure 3.22 Link Status Command Options Field	334	28
Figure 3.23 Link Status Entry	335	29

Figure 3.24	Network Report Command Frame Format	335	
Figure 3.25	Network Report Command Options Field	337	1
Figure 3.26	Report Command Identifier Sub-Field	337	2
Figure 3.27	PAN Identifier Conflict Report	338	3
Figure 3.28	Network Update Command Frame Format	338	4
Figure 3.29	Network Update Command Options Field	339	5
Figure 3.30	Update Command Identifier Sub-Field	340	6
Figure 3.31	PAN Identifier Update	340	7
Figure 3.32	Establishing a New Network	353	8
Figure 3.33	Permitting Devices to Join a Network	354	9
Figure 3.34	Procedure for Joining a Network Through Association .	359	10
Figure 3.35	Procedure for Handling a Join Request	361	11
Figure 3.36	Child Rejoin Procedure	364	12
Figure 3.37	Parent Rejoin Procedure	366	13
Figure 3.38	Joining a Device to a Network Directly	367	14
Figure 3.39	Child Procedure for Joining or Re-Joining a Network Through Orphaning	368	15
Figure 3.40	Parent Procedure for Joining or Re-Joining a Device to its Network Through Orphaning	369	16
Figure 3.41	Address Assignment in an Example Network	375	17
Figure 3.42	Initiation of the Leave Procedure	379	18
Figure 3.43	Procedure for a Device to Remove Its Child	380	19
Figure 3.44	On Receipt of a Leave Command	381	20
Figure 3.45	On Receipt of a Leave Command by a ZED	382	21
Figure 3.46	Typical Frame Structure for a Beaconsing Device	409	22
Figure 3.47	Parent-Child Superframe Positioning Relationship	411	23
Figure 3.48	Broadcast Transaction Message Sequence Chart	415	24
Figure 3.49	Format of the MAC Sub-Layer Beacon Payload	420	25
Figure 4.1	ZigBee Frame with Security on the NWK Level	430	26
Figure 4.2	ZigBee Frame with Security on the APS Level	430	27
Figure 4.3	Secured NWK Layer Frame Format	436	28
Figure 4.4	Sequence Chart for Successful APSME-ESTABLISH- KEY Primitives	454	29
Figure 4.5	Secured APS Layer Frame Format	478	30
Figure 4.6	Sequence Chart for Successful APSME-AUTHENTICATE Primitives	482	31
Figure 4.7	Generic SKKE Frame Command Format	486	32
Figure 4.8	Transport-Key Command Frame	487	33
			34
			35
			36
			37
			38
			39
			40
			41
			42
			43
			44
			45

Figure 4.9 Trust Center Master Key Descriptor Field in Transport-Key Command	488	1
Figure 4.10 Network Key Descriptor Field in Transport-Key Command	488	2
Figure 4.11 Application Master Key Descriptor in Transport-Key Command	489	3
Figure 4.12 Update-Device Command Frame Format	489	4
Figure 4.13 Remove-Device Command Frame Format	490	5
Figure 4.14 Request-Key Command Frame Format	491	6
Figure 4.15 Switch-key Command Frame Format	491	7
Figure 4.16 Entity Authentication Initiator Challenge Frame Format	492	8
Figure 4.17 KeyInfo Field Format	492	9
Figure 4.18 Entity Authentication Responder Challenge Frame Format	493	10
Figure 4.19 KeyInfo Field Format	494	11
Figure 4.20 Entity Authentication Initiator MAC and Data Frame Format	495	12
Figure 4.21 Entity Authentication Responder MAC and Data Frame Format	495	13
Figure 4.22 Tunnel Command Frame Format	496	14
Figure 4.23 Auxiliary Frame Header Format	499	15
Figure 4.24 Security Control Field Format	499	16
Figure 4.25 CCM* Nonce	501	17
Figure 4.26 Example of Joining a Secured Network	505	18
Figure 4.27 Example Standard Security Mode Authentication Procedure	514	19
Figure 4.28 Example High Security Mode Authentication Procedure	516	20
Figure 4.29 Example Network Key-Update Procedure	519	21
Figure 4.30 Example End-to-End Application Key Establishment Procedure	522	22
Figure 4.31 Example Remove-Device Procedure	524	23
Figure 4.32 Example Device-Leave Procedure	525	24
Figure B.1 Symmetric-Key Authenticated Key Agreement Scheme	544	25
Figure B.2 Mutual Symmetric-Key Entity Authentication Scheme	549	26

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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CHAPTER

1

ZIGBEE PROTOCOL OVERVIEW

1.1 Protocol Description

The ZigBee Alliance has developed a very low-cost, very low-power-consumption, two-way, wireless communications standard. Solutions adopting the ZigBee standard will be embedded in consumer electronics, home and building automation, industrial controls, PC peripherals, medical sensor applications, toys, and games.

1.1.1 Scope

This document contains specifications, interface descriptions, object descriptions, protocols and algorithms pertaining to the ZigBee protocol standard, including the application support sub-layer (APS), the ZigBee device objects (ZDO), ZigBee device profile (ZDP), the application framework, the network layer (NWK), and ZigBee security services.

1.1.2 Purpose

The purpose of this document is to provide a definitive description of the ZigBee protocol standard as a basis for future implementations, such that any number of companies incorporating the ZigBee standard into platforms and devices on the basis of this document will produce interoperable, low-cost, and highly usable products for the burgeoning wireless marketplace.

1.1.3 Stack Architecture

The ZigBee stack architecture is made up of a set of blocks called layers. Each layer performs a specific set of services for the layer above. A data entity provides a data transmission service and a management entity provides all other services.

Each service entity exposes an interface to the upper layer through a service access point (SAP), and each SAP supports a number of service primitives to achieve the required functionality.

The IEEE 802.15.4-2003 standard defines the two lower layers: the physical (PHY) layer and the medium access control (MAC) sub-layer. The ZigBee Alliance builds on this foundation by providing the network (NWK) layer and the framework for the application layer. The application layer framework consists of the application support sub-layer (APS) and the ZigBee device objects (ZDO). Manufacturer-defined application objects use the framework and share APS and security services with the ZDO.

IEEE 802.15.4-2003 has two PHY layers that operate in two separate frequency ranges: 868/915 MHz and 2.4 GHz. The lower frequency PHY layer covers both the 868 MHz European band and the 915 MHz band, used in countries such as the United States and Australia. The higher frequency PHY layer is used virtually worldwide. A complete description of the IEEE 802.15.4-2003 PHY layers can be found in [B1].

The IEEE 802.15.4-2003 MAC sub-layer controls access to the radio channel using a CSMA-CA mechanism. Its responsibilities may also include transmitting beacon frames, synchronization, and providing a reliable transmission mechanism. A complete description of the IEEE 802.15.4-2003 MAC sub-layer can be found in [B1].

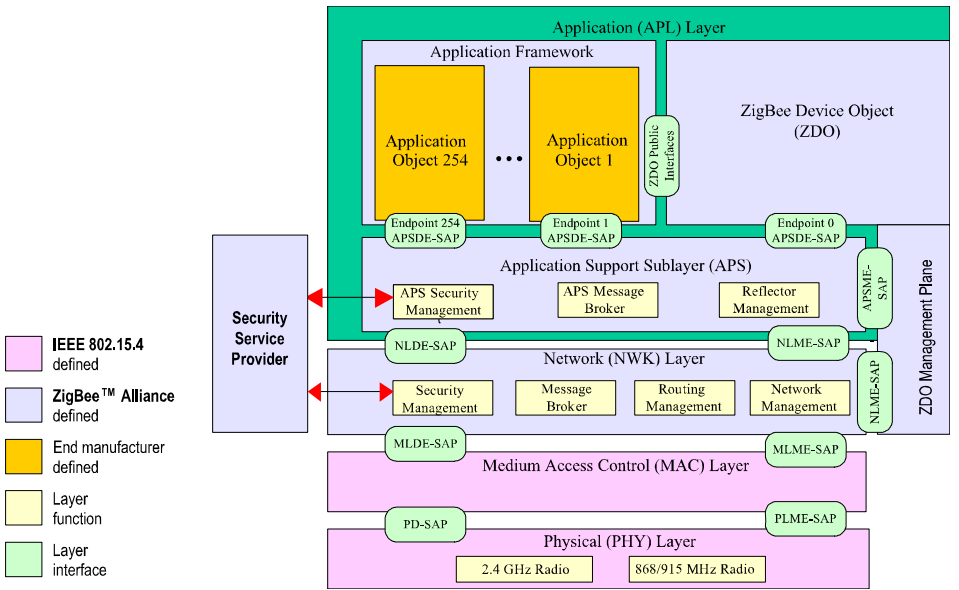


Figure 1.1 Outline of the ZigBee Stack Architecture

1.1.4 Network Topology

The ZigBee network layer (NWK) supports star, tree, and mesh topologies. In a star topology, the network is controlled by one single device called the ZigBee coordinator. The ZigBee coordinator is responsible for initiating and maintaining the devices on the network. All other devices, known as end devices, directly communicate with the ZigBee coordinator. In mesh and tree topologies, the ZigBee coordinator is responsible for starting the network and for choosing certain key network parameters, but the network may be extended through the use of ZigBee routers. In tree networks, routers move data and control messages through the network using a hierarchical routing strategy. Tree networks may employ beacon-oriented communication as described in the IEEE 802.15.4-2003 specification. Mesh networks allow full peer-to-peer communication. ZigBee routers in mesh networks do not currently emit regular IEEE 802.15.4-2003 beacons. This specification describes only intra-PAN networks, that is, networks in which communications begin and terminate within the same network.

1.2 Conventions and Abbreviations

1.2.1 Conventions

1.2.1.1 Symbols and Notation

Notation follows from ANSI X9.63-2001, §2.2 [B7].

1.2.1.2 Integers, Octets, and Their Representation

Throughout Annexes A through D, the representation of integers as octet strings and of octet strings as binary strings shall be fixed. All integers shall be represented as octet strings in most-significant-octet first order. This representation conforms to the convention in Section 4.3 of ANSI X9.63-2001 [B7]. All octets shall be represented as binary strings in most-significant-bit first order.

1.2.1.3 Transmission Order

Unless otherwise indicated, the transmission order of all frames in this specification follows the conventions used in IEEE Std. 802.15.4-2003 [B1]):

- Frame formats are depicted in the order in which they are transmitted by the PHY layer—from left to right—where the leftmost bit is transmitted first in time.
- Bits within each field are numbered from 0 (leftmost, and least significant) to $k-1$ (rightmost, and most significant), where the length of the field is k bits.

- Fields that are longer than a single octet are sent to the PHY in order from the octet containing the lowest numbered bits to the octet containing the highest-numbered bits.

1.2.1.4 Strings and String Operations

A string is a sequence of symbols over a specific set (*e.g.*, the binary alphabet {0,1} or the set of all octets). The length of a string is the number of symbols it contains (over the same alphabet). The empty string has length 0. The right-concatenation of two strings *x* and *y* of length *m* and *n* respectively (notation: *x* // *y*), is the string *z* of length *m+n* that coincides with *x* on its leftmost *m* symbols and with *y* on its rightmost *n* symbols. An octet is a symbol string of length 8. In our context, all octets are strings over the binary alphabet.

1.3 Acronyms and Abbreviations

For the purposes of this standard, the following acronyms and abbreviations apply:

AIB	Application support layer information base
AF	Application framework
APDU	Application support sub-layer protocol data unit
APL	Application layer
APS	Application support sub-layer
APSDE	Application support sub-layer data entity
APSDE-SAP	Application support sub-layer data entity – service access point
APSME	Application support sub-layer management entity
APSME-SAP	Application support sub-layer management entity – service access point
ASDU	APS service data unit
BRT	Broadcast retry timer
BTR	Broadcast transaction record
BT	Broadcast transaction table
CCM*	Enhanced counter with CBC-MAC mode of operation
CSMA-CA	Carrier sense multiple access – collision avoidance
EPID	Extended PAN ID
FFD	Full function device
GTS	Guaranteed time slot

HDR	Header	1
IB	Information base	2
LQI	Link quality indicator	3
LR-WPAN	Low rate wireless personal area network	4
MAC	Medium access control	5
MCPS-SAP	Medium access control common part sub-layer – service access point	6
MIC	Message integrity code	7
MLME-SAP	Medium access control sub-layer management entity – service access point	8
MSC	Message sequence chart	9
MSDU	Medium access control sub-layer service data unit	10
MSG	Message service type	11
NBDT	Network broadcast delivery time	12
NHLE	Next higher layer entity	13
NIB	Network layer information base	14
NLDE	Network layer data entity	15
NLDE-SAP	Network layer data entity – service access point	16
NLME	Network layer management entity	17
NLME-SAP	Network layer management entity – service access point	18
NPDU	Network layer protocol data unit	19
NSDU	Network service data unit	20
NWK	Network	21
OSI	Open systems interconnection	22
PAN	Personal area network	23
PD-SAP	Physical layer data – service access point	24
PDU	Protocol data unit	25
PHY	Physical layer	26
PIB	Personal area network information base	27
PLME-SAP	Physical layer management entity – service access point	28
POS	Personal operating space	29
QOS	Quality of service	30
RFD	Reduced function device	31
RREP	Route reply	32
RREQ	Route request	33

RN	Routing node
SAP	Service access point
SKG	Secret key generation
SKKE	Symmetric-key key establishment
SSP	Security services provider
SSS	Security services specification
WPAN	Wireless personal area network
XML	Extensible markup language
ZB	ZigBee
ZDO	ZigBee device object

1.4 Glossary

1.4.1 Definitions

1.4.1.1 Conformance Levels

The conformance level definitions shall follow those in clause 13, section 1 of the IEEE Style Manual [B13].

Expected: A key word used to describe the behavior of the hardware or software in the design models assumed by this Specification. Other hardware and software design models may also be implemented.

May: A key word indicating a course of action permissible within the limits of the standard (*may equals is permitted to*).

Shall: A key word indicating mandatory requirements to be strictly followed in order to conform to the standard; deviations from shall are prohibited (*shall equals is required to*).

Should: A key word indicating that, among several possibilities, one is recommended as being particularly suitable, without mentioning or excluding others; that a certain course of action is preferred but not necessarily required; or, that (in the negative form) a certain course of action is deprecated but not prohibited (*should equals is recommended that*).

Reserved Codes: A set of codes that are defined in this specification, but not otherwise used. Future specifications may implement the use of these codes. A product implementing this specification shall not generate these codes.

Reserved Fields: A set of fields that are defined in this specification, but are not otherwise used. Products that implement this specification shall zero these fields and shall make no further assumptions about these fields nor perform processing based on their content.

ZigBee Protocol Version: The name of the ZigBee protocol version governed by this specification. The protocol version sub-field of the frame control field in the NWK header of all ZigBee Protocol Stack frames conforming to this specification shall have a value of 0x02 for all ZigBee frames, and a value of 0x03 for the ZigBee Green Power frames.¹ The protocol version support required by various ZigBee specification revisions appears below in Table 1.1.

Table 1.1 ZigBee Protocol Versions

Specification	Protocol Version	Comment
ZigBee Green Power	0x03	ZigBee Green Power feature See reference [B26].
ZigBee Pro ZigBee 2006	0x02	Backwards compatibility not required. ZigBee Pro and ZigBee 2006 compatibility required. ^a
ZigBee 2004	0x01	Original ZigBee version.

a. CCB 1361

A ZigBee device that conforms to this version of the specification may elect to provide backward compatibility with the 2004 revision of the specification. If it so elects, it shall do so by supporting, in addition to the frame formats and features described in this specification version, all frame formats and features as specified in the older version. [All devices in an operating network, regardless of which revisions of the ZigBee specification they support internally, shall, with respect to their external, observable behavior, consistently conform to a single ZigBee protocol version.] A single ZigBee network shall not contain devices that conform, in terms of their external behavior, to multiple ZigBee protocol versions. [The protocol version of the network to join shall be determined by a backwardly compatible device in examining the beacon payload prior to deciding to join the network; or shall be established by the application if the device is a ZigBee coordinator.] A ZigBee device conforming to this specification may elect to support only protocol version 0x02, whereby it shall join only networks that advertise commensurate beacon payload support. A ZigBee device that conforms to this specification shall discard all frames carrying a protocol version sub-field value other than 0x01 to 0x03², and shall process only protocol versions of 0x01 or 0x02,

1. CCB 1361
2. CCB 1361

consistent with the protocol version of the network that the device participates within. A ZigBee device that conforms to this specification shall pass the frames carrying the protocol version sub-field value 0x03 to the ZGP stub (see [B26]), if it supports the ZigBee Green Power, otherwise it shall drop them.³

1.4.1.2 ZigBee Definitions

For the purposes of this standard, the following terms and definitions apply. Terms not defined in this clause can be found in IEEE P802.15.4 §3 [B1] or in ANSI X9.63-2001 §2.1 [B7].

Access control list: This is a table used by a device to determine which devices are authorized to perform a specific function. This table may also store the security material (*e.g.*, cryptographic keys, frame counts, key counts, security level information) used for securely communicating with other devices.

Active network key: This is the key used by a ZigBee device to secure outgoing NWK frames and that is available for use to process incoming NWK frames.

Alternate network key: This is a key available to process incoming NWK frames in lieu of the active network key.

Application domain: This describes a broad area of applications, such as building automation.

Application key: This is a master key or a link key transported by the Trust center to a device for the purpose of securing end-to-end communication.

Application object: This is a component of the top portion of the application layer defined by the manufacturer that actually implements the application.

Application profile: This is a collection of device descriptions, which together form a cooperative application. For instance, a thermostat on one node communicates with a furnace on another node. Together, they cooperatively form a heating application profile.

Application support sub-layer protocol data unit: This is a unit of data that is exchanged between the application support sub-layers of two peer entities.

APS command frame: This is a command frame from the APSME on a device addressed to the peer entity on another device.

Association: This is the service provided by the IEEE 802.15.4-2003 MAC sub-layer that is used to establish membership in a network.

Attribute: This is a data entity which represents a physical quantity or state. This data is communicated to other devices using commands.

3. CCB 1361

Beacon-enabled personal area network: This is a personal area network containing at least one device that transmits beacon frames at a regular interval.

Binding: This is the creation of a unidirectional logical link between a source endpoint/cluster identifier pair and a destination endpoint, which may exist on one or more devices.

Broadcast: This is the transmission of a message to every device in a particular PAN belonging to one of a small number of statically defined broadcast groups, *e.g.* all routers, and within a given transmission radius measured in hops.

Broadcast jitter: This is a random delay time introduced by a device before relaying a broadcast transaction.

Broadcast transaction record: This is a local receipt of a broadcast message that was either initiated or relayed by a device.

Broadcast transaction table: This is a collection of broadcast transaction records.

Cluster: This is an application message, which may be a container for one or more attributes. As an example, the ZigBee Device Profile defines commands and responses. These are contained in Clusters with the cluster identifiers enumerated for each command and response. Each ZigBee Device Profile message is then defined as a cluster. Alternatively, an application profile may create sub-types within the cluster known as attributes. In this case, the cluster is a collection of attributes specified to accompany a specific cluster identifier (sub-type messages.)

Cluster identifier: This is a reference to an enumeration of clusters within a specific application profile or collection of application profiles. The cluster identifier is a 16-bit number unique within the scope of each application profile and identifies a specific cluster. Conventions may be established across application profiles for common definitions of cluster identifiers whereby each application profile defines a set of cluster identifiers identically. Cluster identifiers are designated as inputs or outputs in the simple descriptor for use in creating a binding table.

Coordinator: This is an IEEE 802.15.4-2003 device responsible for associating and disassociating devices into its PAN. A coordinator must be a full function device (FFD).

Data integrity: This is assurance that the data has not been modified from its original form.

Data key: This is a key derived from a link key used to protect data messages.

Device: This is any entity that contains an implementation of the ZigBee protocol stack.

Device application: This is a special application that is responsible for Device operation. The device application resides on endpoint 0 by convention and contains logic to manage the device's networking and general maintenance features. Endpoints 241-254 are reserved for use by the Device application or common application function agreed within the ZigBee Alliance.

Device description: This is a description of a specific device within an application profile. For example, the light sensor device description is a member of the home automation application profile. The device description also has a unique identifier that is exchanged as part of the discovery process.

Direct addressing: This is a mode of addressing in which the destination of a frame is completely specified in the frame itself.

Direct transmission: This is a frame transmission using direct addressing.

Disassociation: This is the service provided by the IEEE 802.15.4-2003 MAC sub-layer that is used to discontinue the membership of a device in a network.

End application: This is for applications that reside on endpoints 1 through 254 on a Device. The end applications implement features that are non-networking and ZigBee protocol related. Endpoints 241 through 254 shall only be used by the End application with approval from the ZigBee Alliance.

End device binding: This is the procedure for creating or removing a binding link initiated by each of the end devices that will form the link. The procedure may or may not involve user intervention.

Endpoint: This is a particular component within a unit. Each ZigBee device may support up to 254 such components.

Endpoint address: This is the address assigned to an endpoint. This address is assigned in addition to the unique, 64-bit IEEE address and 16-bit network address.

Extended PAN ID: This is the globally unique 64-bit PAN identifier of the network. This identifier should be unique among the PAN overlapping in a given area. This identifier is used to avoid PAN ID conflicts between distinct networks.

Information base: This is a collection of variables that define certain behavior in a layer. These variables can be specified or obtained from a layer through its management service.

Key establishment: This is a mechanism that involves the execution of a protocol by two devices to derive a mutually shared secret key.

Key-load key: This is a key derived from a link key used to protect key transport messages carrying a master key.

Key transport: This is a mechanism for communicating a key from one device to another device or other devices.

Key-transport key: This is a key derived from a link key used to protect key transport messages carrying a key other than a master key.

Key update: This is a mechanism implementing the replacement of a key shared amongst two or more devices by means of another key available to that same group.

Local device: This is the initiator of a ZDP command.

Link key: This is a key that is shared exclusively between two, and only two, peer application-layer entities within a PAN.

Master key: This is a shared key used during the execution of a symmetric-key key establishment protocol. The master key is the basis for long-term security between the two devices, and may be used to generate link keys.

Mesh network: This is a network in which the routing of messages is performed as a decentralized, cooperative process involving many peer devices routing on each other's behalf.

Multicast: This is a transmission to every device in a particular PAN belonging to a dynamically defined multicast group, and within a given transmission radius measured in hops.

Multihop network: This is a network, in particular a wireless network, in which there is no guarantee that the transmitter and the receiver of a given message are connected or linked to each other. This implies that intermediate devices must be used as routers.

Non-beacon-enabled personal area network: This is a personal area network that does not contain any devices that transmit beacon frames at a regular interval.

Neighbor table: This is a table used by a ZigBee device to keep track of other devices within the POS.

Network address: This is the address assigned to a device by the network layer and used by the network layer for routing messages between devices.

Network broadcast delivery time: This is the time required by a broadcast transaction to reach every device of a given network.

Network manager: This is a ZigBee device that implements network management functions as described in Clause 3, including PAN ID conflict resolution and frequency agility measures in the face of interference.

Network protocol data unit: This is a unit of data that is exchanged between the network layers of two peer entities.

Network service data unit: This is the information that is delivered as a unit through a network service access point.

Node: This is a collection of independent device descriptions and applications residing in a single unit and sharing a common 802.15.4 radio.

Normal operating state: This is the processing which occurs after all startup and initialization processing has occurred and prior to initiation of shutdown processing.

NULL: a parameter or variable value that means unspecified, undefined, or unknown. The exact value of NULL is implementation-specific, and must not conflict with any other parameters or values.

Octet: eight bits of data, used as a synonym for a byte.

OctetDuration: transmission time (in seconds) of an octet on PHY layer. This time is calculated as $8/\text{phyBitRate}$ where phyBitRate can be found in Table 1 of IEEE 802.15.4 2003 standard. To get milliseconds from N OctetDurations for 2.4 GHz the follow formula has to be used: $N \cdot (8/250000) \cdot 1000$ where 250000 bit rate on 2.4 GHz and 8 number of bits in one octet.⁴

One-way function: a function whose forward computation is much easier to perform than its inverse.⁵

Orphaned device: a device, typically a ZigBee end device, that has lost communication with the ZigBee device through which it has its PAN membership.

PAN coordinator: the principal controller of an IEEE 802.15.4-2003-based network that is responsible for network formation. The PAN coordinator must be a full function device (FFD).

PAN information base: a collection of variables in the IEEE 802.15.4-2003 standard that are passed between layers, in order to exchange information. This database may include the access control list, which stores the security material.

Personal operating space: the area within reception range of a single device.

Private method: attributes and commands which are accessible to ZigBee device objects only and unavailable to the end applications.

Protocol data unit: the unit of data that is exchanged between two peer entities.

Public method: attributes and commands which are accessible to end applications.

4. ZigBee Document 12-0220-04

5. ZigBee Document 12-0220-04

Radio: the IEEE 802.15.4-2003 radio that is part of every ZigBee device.

Remote device: the target of a ZDP command.

Route discovery: an operation in which a ZigBee coordinator or ZigBee router attempts to discover a route to a remote device by issuing a route request command frame.

Route discovery table: a table used by a ZigBee coordinator or ZigBee router to store temporary information used during route discovery.

Route reply: a ZigBee network layer command frame used to reply to route requests.

Route request: a ZigBee network layer command frame used to discover paths through the network over which subsequent messages may be delivered.

Routing table: a table in which a ZigBee coordinator or ZigBee router stores information required to participate in the routing of frames.

Service discovery: the ability of a device to locate services of interest.

Stack profile: an agreement by convention outside the scope of the ZigBee specification on a set of additional restrictions with respect to features declared optional by the specification itself.

Symmetric-key key establishment: a mechanism by which two parties establish a shared secret, based on a pre-shared secret (a so-called master key).

Trust center: the device trusted by devices within a ZigBee network to distribute keys for the purpose of network and end-to-end application configuration management.

Unicast: the transmission of a message to a single device in a network.

ZigBee coordinator: an IEEE 802.15.4-2003 PAN coordinator.

ZigBee device object: the portion of the application layer responsible for defining the role of the device within the network (*e.g.*, ZigBee coordinator or end device), initiating and/or responding to binding and discovery requests, and establishing a secure relationship between network devices.

ZigBee end device: an IEEE 802.15.4-2003 RFD or FFD participating in a ZigBee network, which is neither the ZigBee coordinator nor a ZigBee router.

ZigBee router: an IEEE 802.15.4-2003 FFD participating in a ZigBee network, which is not the ZigBee coordinator but may act as an IEEE 802.15.4-2003 coordinator within its personal operating space, that is capable of routing messages between devices and supporting associations.

1.5 References

The following standards contain provisions, which, through reference in this document, constitute provisions of this standard. Normative references are given in “ZigBee/IEEE References,” and “Normative References,” and informative references are given in “Informative References.” At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the references, as indicated in this sub-clause.

1.5.1 ZigBee/IEEE References

[B1] Institute of Electrical and Electronics Engineers, Inc., IEEE Std. 802.15.4-2003, IEEE Standard for Information Technology — Telecommunications and Information Exchange between Systems — Local and Metropolitan Area Networks — Specific Requirements — Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs). New York: IEEE Press. 2003.

[B2] IEEE 754-1985, IEEE Standard for Binary Floating-Point Arithmetic, IEEE, 1985.

[B3] Document 03285r0: Suggestions for the Improvement of the IEEE 802.15.4 Standard, July 2003.

[B4] Document 02055r4: Network Requirements Definition, August 2003.

1.5.2 Normative References

[B5] ISO/IEC 639-1:2002 Codes for the representation of names of languages — Part 1: Alpha-2 code.

[B6] ISO/IEC 646:199 Information technology — ISO 7-bit coded character set for information interchange.

[B7] ANSI X9.63-2001, Public Key Cryptography for the Financial Services Industry - Key Agreement and Key Transport Using Elliptic Curve Cryptography, American Bankers Association, November 20, 2001. Available from <http://www.ansi.org>.

[B8] FIPS Pub 197, Advanced Encryption Standard (AES), Federal Information Processing Standards Publication 197, US Department of Commerce/N.I.S.T, Springfield, Virginia, November 26, 2001. Available from <http://csrc.nist.gov/>.

[B9] FIPS Pub 198, The Keyed-Hash Message Authentication Code (HMAC), Federal Information Processing Standards Publication 198, US Department of Commerce/N.I.S.T., Springfield, Virginia, March 6, 2002. Available from <http://csrc.nist.gov/>.

[B10] ISO/IEC 9798-2, Information Technology - Security Techniques — Entity Authentication Mechanisms — Part 2: Mechanisms Using Symmetric Encipherment Algorithms, International Standardization Organization, Geneva, Switzerland, 1994 (first edition). Available from <http://www.iso.org/>.

[B11] NIST Pub 800-38A 2001 ED, Recommendation for Block Cipher Modes of Operation — Methods and Techniques, NIST Special Publication 800-38A, 2001 Edition, US Department of Commerce/N.I.S.T., December 2001. Available from <http://csrc.nist.gov/>.

[B12] NIST, Random Number Generation and Testing. Available from <http://csrc.nist.gov/rng/>.

1.5.3 Informative References

[B13] FIPS Pub 140-2, Security requirements for Cryptographic Modules, US Department of Commerce/N.I.S.T., Springfield, Virginia, June 2001 (supersedes FIPS Pub 140-1). Available from <http://csrc.nist.gov/>.

[B14] IEEE Standards Style Manual, published and distributed in May 2000 and revised on September 20, 2001. Available from <http://standards.ieee.org/guides/style/>.

[B15] ISO/IEC 7498-1:1994 Information technology — Open systems interconnection — Basic reference model: The basic model.

[B16] ISO/IEC 10731:1994, Information technology — Open Systems Interconnection — Conventions for the definition of OSI services.

[B17] ISO/IEC 9646-1:1991, Information technology — Open systems Interconnection — Conformance testing methodology and framework — Part 1: General concepts.

[B18] ISO/IEC 9646-7:1995, Information technology — Open Systems Interconnection — Conformance testing methodology and framework — Part 7. Implementation conformance statements.

[B19] A.J. Menezes, P.C. van Oorschot, S.A. Vanstone, *Handbook of Applied Cryptography*, Boca Raton: CRC Press, 1997.

[B20] FIPS Pub 113, Computer Data Authentication, Federal Information Processing Standard Publication 113, US Department of Commerce/N.I.S.T., May 30, 1985. Available from <http://csrc.nist.gov/>.

[B21] R. Housley, D. Whiting, N. Ferguson, Counter with CBC-MAC (CCM), submitted to N.I.S.T., June 3, 2002. Available from <http://csrc.nist.gov/encryption/modules/proposedmodes/>.

[B22] J. Jonsson, On the Security of CTR + CBC-MAC, in Proceedings of Selected Areas in Cryptography — SAC 2002, K. Nyberg, H. Heys, Eds., Lecture Notes in Computer Science, Vol. 2595, pp. 76-93, Berlin: Springer, 2002.

[B23] J. Jonsson, On the Security of CTR + CBC-MAC, NIST Mode of Operation — Additional CCM Documentation. Available from <http://csrc.nist.gov/encryption/modes/proposedmodes/>.

[B24] P. Rogaway, D. Wagner, A Critique of CCM, IACR ePrint Archive 2003-070, April 13, 2003.

[B25] ZigBee Document 053298- CSG Framework Profile Identifier Database⁶

[B26] ZigBee Document 09-5499r22 – Green Power Specification⁷

6. CCB 1224

7. CCB 1361

CHAPTER

2

APPLICATION LAYER SPECIFICATION

2.1 General Description

The ZigBee stack architecture includes a number of layered components including the IEEE 802.15.4-2003 Medium Access Control (MAC) layer, Physical (PHY) layer, and the ZigBee Network (NWK) layer. Each component provides an application with its own set of services and capabilities. Although this chapter may refer to other components within the ZigBee stack architecture, its primary purpose is to describe the component labeled Application (APL) Layer shown in Figure 1.1 of “ZigBee Protocol Overview.”

As shown in Figure 1.1, the ZigBee application layer consists of the APS sub-layer, the ZDO (containing the ZDO management plane), and the manufacturer-defined application objects.

2.1.1 Application Support Sub-Layer

The application support sub-layer (APS) provides an interface between the network layer (NWK) and the application layer (APL) through a general set of services that are used by both the ZDO and the manufacturer-defined application objects. The services are provided by two entities:

- The APS data entity (APSD) through the APSD service access point (APSD-SAP).
- The APS management entity (APSM) through the APSM service access point (APSM-SAP).

The APSD provides the data transmission service between two or more application entities located on the same network.

The APSME provides a variety of services to application objects including security services and binding of devices. It also maintains a database of managed objects, known as the APS information base (AIB).

2.1.2 Application Framework

The application framework in ZigBee is the environment in which application objects are hosted on ZigBee devices.

Up to 254 distinct application objects can be defined, each identified by an endpoint address from 1 to 254. Two additional endpoints are defined for APSDE-SAP usage: endpoint 0 is reserved for the data interface to the ZDO, and endpoint 255 is reserved for the data interface function to broadcast data to all application objects. Endpoints 241-254 are assigned by the ZigBee Alliance and shall not be used without approval.

2.1.2.1 Application Profiles

Application profiles are agreements for messages, message formats, and processing actions that enable developers to create an interoperable, distributed application employing application entities that reside on separate devices. These application profiles enable applications to send commands, request data, and process commands and requests.

2.1.2.2 Clusters

Clusters are identified by a cluster identifier, which is associated with data flowing out of, or into, the device. Cluster identifiers are unique within the scope of a particular application profile.

2.1.3 ZigBee Device Objects

The ZigBee device objects (ZDO), represent a base class of functionality that provides an interface between the application objects, the device profile, and the APS. The ZDO is located between the application framework and the application support sub-layer. It satisfies common requirements of all applications operating in a ZigBee protocol stack. The ZDO is responsible for the following:

- Initializing the application support sub-layer (APS), the network layer (NWK), and the Security Service Provider.
- Assembling configuration information from the end applications to determine and implement discovery, security management, network management, and binding management.

The ZDO presents public interfaces to the application objects in the application framework layer for control of device and network functions by the application objects. The ZDO interfaces with the lower portions of the ZigBee protocol stack, on endpoint 0, through the APSDE-SAP for data, and through the APSME-SAP and NLME-SAP for control messages. The public interface provides address management of the device, discovery, binding, and security functions within the application framework layer of the ZigBee protocol stack. The ZDO is fully described in clause 2.5.

2.1.3.1 Device Discovery

Device discovery is the process whereby a ZigBee device can discover other ZigBee devices. There are two forms of device discovery requests: IEEE address requests and NWK address requests. The IEEE address request is unicast to a particular device and assumes the NWK address is known. The NWK address request is broadcast and carries the known IEEE address as data payload.

2.1.3.2 Service Discovery

Service discovery is the process whereby the capabilities of a given device are discovered by other devices. Service discovery can be accomplished by issuing a query for each endpoint on a given device or by using a match service feature (either broadcast or unicast). The service discovery facility defines and utilizes various descriptors to outline the capabilities of a device.

Service discovery information may also be cached in the network in the case where the device proffering a particular service may be inaccessible at the time the discovery operation takes place.

2.2 ZigBee Application Support (APS) Sub-Layer

2.2.1 Scope

This clause specifies the portion of the application layer providing the service specification and interface to both the manufacturer-defined application objects and the ZigBee device objects. The specification defines a data service to allow the application objects to transport data, and a management service providing mechanisms for binding. In addition, it also defines the application support sub-layer frame format and frame-type specifications.

2.2.2 Purpose

The purpose of this clause is to define the functionality of the ZigBee application support (APS) sub-layer. This functionality is based on both the driver

functionality necessary to enable correct operation of the ZigBee network layer and the functionality required by the manufacturer-defined application objects.

2.2.3 Application Support (APS) Sub-Layer Overview

The application support sub-layer provides the interface between the network layer and the application layer through a general set of services for use by both the ZigBee device object (ZDO) and the manufacturer-defined application objects. These services are offered via two entities: the data service and the management service. The APS data entity (APSDE) provides the data transmission service via its associated SAP, the APSDE-SAP. The APS management entity (APSME) provides the management service via its associated SAP, the APSME-SAP, and maintains a database of managed objects known as the APS information base (AIB).

2.2.3.1 Application Support Sub-Layer Data Entity (APSDE)

The APSDE shall provide a data service to the network layer and both ZDO and application objects to enable the transport of application PDUs between two or more devices. The devices themselves must be located on the same network.

The APSDE will provide the following services:

- **Generation of the application level PDU (APDU):** the APSDE shall take an application PDU and generate an APS PDU by adding the appropriate protocol overhead.
- **Binding:** once two devices are bound, the APSDE shall be able to transfer a message from one bound device to the second device.
- **Group address filtering:** this provides the ability to filter group-addressed messages based on endpoint group membership.
- **Reliable transport:** this increases the reliability of transactions above that available from the NWK layer alone by employing end-to-end retries.
- **Duplicate rejection:** messages offered for transmission will not be received more than once.
- **Fragmentation:** this enables segmentation and reassembly of messages longer than the payload of a single NWK layer frame.

2.2.3.2 Application Support Sub-Layer Management Entity (APSME)

The APSME shall provide a management service to allow an application to interact with the stack.

The APSME shall provide the ability to match two devices together based on their services and their needs. This service is called the binding service, and the APSME shall be able to construct and maintain a table to store this information.

In addition, the APSME will provide the following services:

- **Binding management:** this is the ability to match two devices together based on their services and their needs.
- **AIB management:** the ability to get and set attributes in the device's AIB.
- **Security:** the ability to set up authentic relationships with other devices through the use of secure keys.
- **Group management:** this provides the ability to declare a single address shared by multiple devices, to add devices to the group, and to remove devices from the group.

2.2.4 Service Specification

The APS sub-layer provides an interface between a next higher layer entity (NHLE) and the NWK layer. The APS sub-layer conceptually includes a management entity called the APS sub-layer management entity (APSME). This entity provides the service interfaces through which sub-layer management functions may be invoked. The APSME is also responsible for maintaining a database of managed objects pertaining to the APS sub-layer. This database is referred to as the APS sub-layer information base (AIB). Figure 2.1 depicts the components and interfaces of the APS sub-layer.

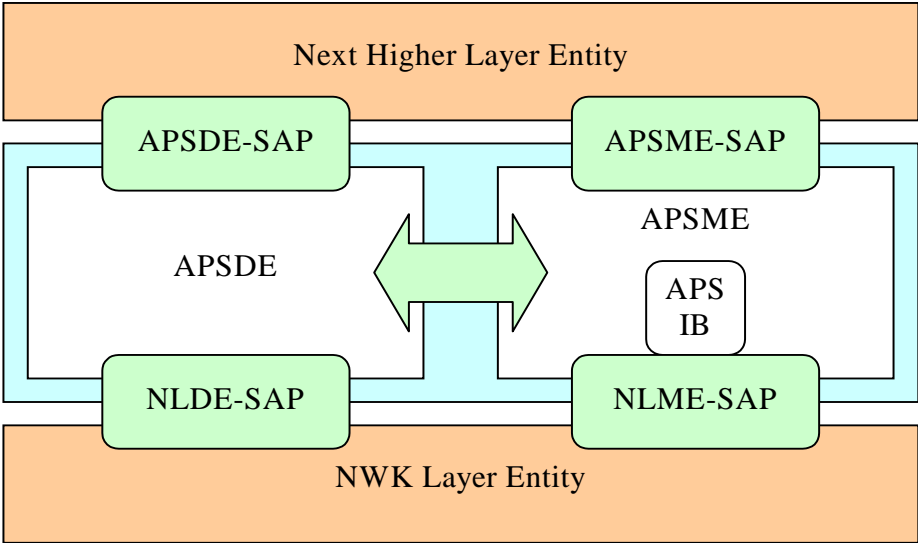


Figure 2.1 The APS Sub-Layer Reference Model

The APS sub-layer provides two services, accessed through two service access points (SAPs). These are the APS data service, accessed through the APS sub-layer data entity SAP (APSDE-SAP), and the APS management service, accessed through the APS sub-layer management entity SAP (APSME-SAP). These two services provide the interface between the NHLE and the NWK layer, via the NLDE-SAP and, to a limited extent, NLME-SAP interfaces (see sub-clause 3.1). The NLME-SAP interface between the NWK layer and the APS sub-layer supports only the NLME-GET and NLME-SET primitives; all other NLME-SAP primitives are available only via the ZDO (see sub-clause 2.5). In addition to these external interfaces, there is also an implicit interface between the APSME and the APSDE that allows the APSME to use the APS data service.

2.2.4.1 APS Data Service

The APS sub-layer data entity SAP (APSDE-SAP) supports the transport of application protocol data units between peer application entities. Table 2.1 lists the primitives supported by the APSDE-SAP. Each of these primitives will be discussed in the following sub-clauses.

Table 2.1 APSDE-SAP Primitives

APSDE-SAP Primitive	Request	Confirm	Indication
APSDE-DATA	2.2.4.1.1	2.2.4.1.2	2.2.4.1.3

2.2.4.1.1 APSDE-DATA.request

This primitive requests the transfer of a NHLE PDU (ASDU) from the local NHLE to one or more peer NHLE entities.

2.2.4.1.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSDE-DATA.request	{
	DstAddrMode,
	DstAddress,
	DstEndpoint,
	ProfileId,
	ClusterId,
	SrcEndpoint,
	ADSULength,
	ASDU,
	TxOptions,
	RadiusCounter
	}

Table 2.2 specifies the parameters for the APSDE-DATA.request primitive.

Table 2.2 APSDE-DATA.request Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive and of the APDU to be transferred. This parameter can take one of the non-reserved values from the following list: 0x00 = DstAddress and DstEndpoint not present 0x01 = 16-bit group address for DstAddress; DstEndpoint not present 0x02 = 16-bit address for DstAddress and DstEndpoint present 0x03 = 64-bit extended address for DstAddress and DstEndpoint present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode parameter	The individual device address or group address of the entity to which the ASDU is being transferred.
DstEndpoint	Integer	0x00 – 0xff	This parameter shall be present if, and only if, the DstAddrMode parameter has a value of 0x02 or 0x03 and, if present, shall be either the number of the individual endpoint of the entity to which the ASDU is being transferred or the broadcast endpoint (0xff).
ProfileId	Integer	0x0000 – 0xffff	The identifier of the profile for which this frame is intended.
ClusterId	Integer	0x0000 – 0xffff	The identifier of the object for which this frame is intended.
SrcEndpoint	Integer	0x00 – 0xfe	The individual endpoint of the entity from which the ASDU is being transferred.
ADSULength	Integer	0x00 - 256*(Nsdulength - apscMinHeaderOverhead)	The number of octets comprising the ASDU to be transferred. The maximum length of an individual APS frame payload is given as Nsdulength - <i>apscMinHeaderOverhead</i> . Assuming fragmentation is used, there can be 256 such blocks comprising a single maximum sized ASDU.

Table 2.2 APSDE-DATA.request Parameters (Continued)

Name	Type	Valid Range	Description
Asdu	Set of octets	-	The set of octets comprising the ASDU to be transferred.
TxOptions	Bitmap	0000 0000 – 0001 1111 ^a	The transmission options for the ASDU to be transferred. These are a bitwise OR of one or more of the following: 0x01 = Security enabled transmission 0x02 = Use NWK key 0x04 = Acknowledged transmission 0x08 = Fragmentation permitted 0x10 = Include extended nonce in APS security frame. ^b
Radius	Unsigned integer	0x00-0xff	The distance, in hops, that a transmitted frame will be allowed to travel through the network.

a. CCB 1184

b. CCB 1184

2.2.4.1.1.2 When Generated

This primitive is generated by a local NHLE whenever a data PDU (ASDU) is to be transferred to one or more peer NHLEs.

2.2.4.1.1.3 Effect on Receipt

On receipt of this primitive, the APS sub-layer entity begins the transmission of the supplied ASDU.

If the DstAddrMode parameter is set to 0x00 and this primitive was received by the APSDE of a device supporting a binding table, a search is made in the binding table with the endpoint and cluster identifiers specified in the SrcEndpoint and ClusterId parameters, respectively, for associated binding table entries. If no binding table entries are found, the APSDE issues the APSDE-DATA.confirm primitive with a status of NO_BOUND_DEVICE. If one or more binding table entries are found, then the APSDE examines the destination address information in each binding table entry. If this indicates a device itself, then the APSDE shall issue an APSDE-DATA.indication primitive to the next higher layer with the DstEndpoint parameter set to the destination endpoint identifier in the binding table entry. Otherwise, the APSDE constructs the APDU with the endpoint information from the binding table entry, if present, and uses the destination address information from the binding table entry when transmitting the frame via the NWK layer. If more than one binding table entry is present, then the APSDE

processes each binding table entry as described above; until no more binding table entries remain. If this primitive was received by the APSDE of a device that does not support a binding table, the APSDE issues the APSDE-DATA.confirm primitive with a status of NOT_SUPPORTED.

If the DstAddrMode parameter is set to 0x03, the DstAddress parameter contains an extended 64-bit IEEE address and must first be mapped to a corresponding 16-bit NWK address by using the *nwkAddressMap* attribute of the NIB (see Table 3.43). If a corresponding 16-bit NWK address could not be found, the APSDE issues the APSDE-DATA.confirm primitive with a status of NO_SHORT_ADDRESS. If a corresponding 16-bit NWK address is found, it will be used in the invocation of the NLDE-DATA.request primitive and the value of the DstEndpoint parameter will be placed in the resulting APDU. The delivery mode sub-field of the frame control field of the APS header shall have a value of 0x00 in this case.

If the DstAddrMode parameter has a value of 0x01, indicating group addressing, the DstAddress parameter will be interpreted as a 16-bit group address. This address will be placed in the group address field of the APS header, the DstEndpoint parameter will be ignored, and the destination endpoint field will be omitted from the APS header. The delivery mode sub-field of the frame control field of the APS header shall have a value of 0x03 in this case.

If the DstAddrMode parameter is set to 0x02, the DstAddress parameter contains a 16-bit NWK address, and the DstEndpoint parameter is supplied. The next higher layer should only employ DstAddrMode of 0x02 in cases where the destination NWK address is employed for immediate application responses and the NWK address is not retained for later data transmission requests.

The application may limit the number of hops a transmitted frame is allowed to travel through the network by setting the RadiusCounter parameter of the NLDE-DATA.request primitive to a non-zero value.

If the DstAddrMode parameter has a value of 0x01, indicating group addressing, or the DstAddrMode parameter has a value of 0x00 and the corresponding binding table entry contains a group address, then the APSME will check the value of the *nwkUseMulticast* attribute of the NIB (see Table 3.44). If this attribute has a value of FALSE, then the delivery mode sub-field of the frame control field of the resulting APDU will be set to 0b11, the 16-bit address of the destination group will be placed in the group address field of the APS header of the outgoing frame, and the NSDU frame will be transmitted as a broadcast. A value of 0xffff, that is, the broadcast to all devices for which macRxOnWhenIdle = TRUE, will be supplied for the DstAddr parameter of the NLDE-DATA.request that is used to transmit the frame. If the *nwkUseMulticast* attribute has a value of TRUE, then the outgoing frame will be transmitted using NWK layer multicast, with the delivery mode sub-field of the frame control field of the APDU set to 0b10, the destination endpoint field set to 0xff, and the group address not placed in the APS header.

If the TxOptions parameter specifies that secured transmission is required, the APS sub-layer shall use the security service provider (see sub-clause 4.2.3) to secure the ASDU. If the security processing fails, the APSDE shall issue the APSDE-DATA.confirm primitive with a status of SECURITY_FAIL.

The APSDE transmits the constructed frame by issuing the NLDE-DATA.request primitive to the NWK layer. When the APSDE has completed all operations related to this transmission request, including transmitting frames as required, any retransmissions, and the receipt or timeout of any acknowledgements, then the APSDE shall issue the APSDE-DATA.confirm primitive (see sub-clause 2.2.4.1.2). If one or more NLDE-DATA.confirm primitives failed, then the Status parameter shall be set to that received from the NWK layer. Otherwise, if one or more APS acknowledgements were not correctly received, then the Status parameter shall be set to NO_ACK. If the ASDU was successfully transferred to all intended targets, then the Status parameter shall be set to SUCCESS.

If NWK layer multicast is being used, the NonmemberRadius parameter of the NLDE-DATA.request primitive shall be set to *apsNonmemberRadius*.

The APSDE will ensure that route discovery is always enabled at the network layer by setting the DiscoverRoute parameter of the NLDE-DATA.request primitive to 0x01, each time it is issued.

If the ASDU to be transmitted is larger than will fit in a single frame and fragmentation is not possible, then the ASDU is not transmitted and the APSDE shall issue the APSDE-DATA.confirm primitive with a status of ASDU_TOO_LONG. Fragmentation is not possible if either an acknowledged transmission is not requested, or if the fragmentation permitted flag in the TxOptions field is set to 0, or if the ASDU is too large to be handled by the APSDE.

If the ASDU to be transmitted is larger than will fit in a single frame, an acknowledged transmission is requested, and the fragmentation permitted flag of the TxOptions field is set to 1, and the ASDU is not too large to be handled by the APSDE, then the ASDU shall be fragmented across multiple APDUs, as described in sub-clause 2.2.8.4.5. Transmission and security processing where requested, shall be carried out for each individual APDU independently. Note that fragmentation shall not be used unless relevant higher-layer documentation and/or interactions explicitly indicate that fragmentation is permitted for the frame being sent, and that the other end is able to receive the fragmented transmission, both in terms of number of blocks and total transmission size.

2.2.4.1.2 APSDE-DATA.confirm

The primitive reports the results of a request to transfer a data PDU (ASDU) from a local NHLE to one or more peer NHLEs.

2.2.4.1.2.1 Semantics of the Service Primitive

This semantics of this primitive are as follows:

APSDE-DATA.confirm	{
	DstAddrMode,
	DstAddress,
	DstEndpoint,
	SrcEndpoint,
	Status,
	TxTime
	}

Table 2.3 specifies the parameters for the APSDE-DATA.confirm primitive.

Table 2.3 APSDE-DATA.confirm Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive and of the APDU to be transferred. This parameter can take one of the non-reserved values from the following list: 0x00 = DstAddress and DstEndpoint not present 0x01 = 16-bit group address for DstAddress; DstEndpoint not present 0x02 = 16-bit address for DstAddress and DstEndpoint present 0x03= 64-bit extended address for DstAddress and DstEndpoint present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode parameter	The individual device address or group address of the entity to which the ASDU is being transferred.
DstEndpoint	Integer	0x00 – 0xff	This parameter shall be present if, and only if, the DstAddrMode parameter has a value of 0x02 or 0x03 and, if present, shall be the number of the individual endpoint of the entity to which the ASDU is being transferred.

Table 2.3 APSDE-DATA.confirm Parameters

SrcEndpoint	Integer	0x00 – 0xfe	The individual endpoint of the entity from which the ASDU is being transferred.
Status	Enumeration	SUCCESS, NO_SHORT_ADDRESS, NO_BOUND_DEVICE, SECURITY_FAIL, NO_ACK, ASDU_TOO_LONG or any status values returned from the NLDE- DATA.confirm primitive	The status of the corresponding request.
TxTime	Integer	Implementation specific	A time indication for the transmitted packet based on the local clock, as provided by the NWK layer.

2.2.4.1.2.2 When Generated

This primitive is generated by the local APS sub-layer entity in response to an APSDE-DATA.request primitive. This primitive returns a status of either SUCCESS, indicating that the request to transmit was successful, or an error code of NO_SHORT_ADDRESS, NO_BOUND_DEVICE, SECURITY_FAIL, ASDU_TOO_LONG, or any status values returned from the NLDE-DATA.confirm primitive. The reasons for these status values are fully described in 2.2.4.1.1.3.

2.2.4.1.2.3 Effect on Receipt

On receipt of this primitive, the next higher layer of the initiating device is notified of the result of its request to transmit. If the transmission attempt was successful, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter will indicate the error.

2.2.4.1.3 APSDE-DATA.indication

This primitive indicates the transfer of a data PDU (ASDU) from the APS sub-layer to the local application entity.

2.2.4.1.3.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSDE-DATA.indication	{
	DstAddrMode,
	DstAddress,
	DstEndpoint,
	SrcAddrMode,
	SrcAddress,
	SrcEndpoint,
	ProfileId,
	ClusterId,
	asduLength,
	asdu,
	Status,
	SecurityStatus,
	LinkQuality,
	RxTime
	}

Table 2.4 specifies the parameters for the APSDE-DATA.indication primitive.

Table 2.4 APSDE-DATA.indication Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x00 - 0xff	The addressing mode for the destination address used in this primitive and of the APDU that has been received. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddress; DstEndpoint not present 0x02 = 16-bit address for DstAddress and DstEndpoint present 0x03 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode parameter	The individual device address or group address to which the ASDU is directed.
DstEndpoint	Integer	0x00 – 0xfe	The target endpoint on the local entity to which the ASDU is directed.

Table 2.4 APSDE-DATA.indication Parameters

Name	Type	Valid Range	Description
SrcAddrMode	Integer	0x00 – 0xff	The addressing mode for the source address used in this primitive and of the APDU that has been received. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = reserved 0x02 = 16-bit short address for SrcAddress and SrcEndpoint present 0x03 = 64-bit extended address for SrcAddress and SrcEndpoint present 0x04 – 0xff = reserved
SrcAddress	Address	As specified by the SrcAddrMode parameter	The individual device address of the entity from which the ASDU has been received.
SrcEndpoint	Integer	0x00 – 0xfe	The number of the individual endpoint of the entity from which the ASDU has been received.
ProfileId	Integer	0x0000 - 0xffff	The identifier of the profile from which this frame originated.
ClusterId	Integer	0x0000-0xffff	The identifier of the received object.
asduLength	Integer		The number of octets comprising the ASDU being indicated by the APSDE.
asdu	Set of octets	-	The set of octets comprising the ASDU being indicated by the APSDE.
Status	Enumeration	SUCCESS, DEFRAG_UNSU PPORTED, DEFRAG_DEFE RRED or any status returned from the security processing of the frame	The status of the incoming frame processing.

Table 2.4 APSDE-DATA.indication Parameters

Name	Type	Valid Range	Description
SecurityStatus	Enumeration	UNSECURED, SECURED_NW K_KEY, SECURED_LIN K_KEY	UNSECURED if the ASDU was received without any security. SECURED_NWK_KEY if the received ASDU was secured with the NWK key. SECURED_LINK_KEY if the ASDU was secured with a link key.
LinkQuality	Integer	0x00 - 0xff	The link quality indication delivered by the NLDE.
RxTime	Integer	Implementation specific	A time indication for the received packet based on the local clock, as provided by the NWK layer.

2.2.4.1.3.2 When Generated

This primitive is generated by the APS sub-layer and issued to the next higher layer on receipt of an appropriately addressed data frame from the local NWK layer entity or following receipt of an APSDE-DATA.request in which the DstAddrMode parameter was set to 0x00 and the binding table entry has directed the frame to the device itself. If the frame control field of the ASDU header indicates that the frame is secured, security processing shall be done as specified in sub-clause 4.2.3.

This primitive is generated by the APS sub-layer entity and issued to the next higher layer entity on receipt of an appropriately addressed data frame from the local network layer entity, via the NLDE-DATA.indication primitive.

If the frame control field of the APDU header indicates that the frame is secured, then security processing must be undertaken as specified in sub-clause 4.2.3. If the security processing fails, the APSDE sets the Status parameter to the security error code returned from the security processing.

If the frame is not secured or the security processing was successful, the APSDE must check for the frame being fragmented. If the extended header is included in the APDU header and the fragmentation sub-field of the extended frame control field indicates that the frame is fragmented but this device does not support fragmentation, the APSDE sets the Status parameter to DEFRAG_-UNSUPPORTED. If the extended header is included in the APDU header, the fragmentation sub-field of the extended frame control field indicates that the frame is fragmented and the device supports fragmentation, but is not currently able to defragment the frame, the APSDE sets the Status parameter to DEFRAG_-DEFERRED.

Under all other circumstances, the APSDE sets the Status parameter to SUCCESS.

If the Status parameter is not set to SUCCESS, the APSDE sets the ASDULength parameter to 0 and the ASDU parameter to the null set of bytes.

The APS sub-layer entity shall attempt to map the source address from the received frame to its corresponding extended 64-bit IEEE address by using the *nwkAddressMap* attribute of the NIB (see Table 3.43). If a corresponding 64-bit IEEE address was found, the APSDE issues this primitive with the SrcAddrMode parameter set to 0x03 and the SrcAddress parameter set to the corresponding 64-bit IEEE address. If a corresponding 64-bit IEEE address was not found, the APSDE issues this primitive with the SrcAddrMode parameter set to 0x02, and the SrcAddress parameter set to the 16-bit source address as contained in the received frame.

2.2.4.1.3.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the arrival of data at the device.

2.2.4.2 APS Management Service

The APS management entity SAP (APSME-SAP) supports the transport of management commands between the next higher layer and the APSME. Table 2.5 summarizes the primitives supported by the APSME through the APSME-SAP interface. See the following sub-clauses for more details on the individual primitives.

Table 2.5 Summary of the Primitives Accessed Through the APSME-SAP

Name	Request	Indication	Response	Confirm
APSME-BIND	2.2.4.3.1			2.2.4.3.2
APSME-UNBIND	2.2.4.3.3			2.2.4.3.4
APSME-GET	2.2.4.4.1			2.2.4.4.2
APSME-SET	2.2.4.4.3			2.2.4.4.4
APSME-ADD-GROUP	2.2.4.5.1			2.2.4.5.2
APSME-REMOVE-GROUP	2.2.4.5.3			2.2.4.5.4
APSME-REMOVE-ALL-GROUPS	2.2.4.5.5			2.2.4.5.6

2.2.4.3 Binding Primitives

This set of primitives defines how the next higher layer of a device can add (commit) a binding record to its local binding table or remove a binding record from its local binding table.

Only a device supporting a binding table or a binding table cache may process these primitives. If any other device receives these primitives from their next higher layer, the primitives should be rejected.

2.2.4.3.1 APSME-BIND.request

This primitive allows the next higher layer to request to bind two devices together, or to bind a device to a group, by creating an entry in its local binding table, if supported.

2.2.4.3.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-BIND.request	{
	SrcAddr,
	SrcEndpoint,
	ClusterId,
	DstAddrMode,
	DstAddr,
	DstEndpoint
	}

Table 2.6 specifies the parameters for the APSME-BIND.request primitive.

Table 2.6 APSME-BIND.request Parameters

Name	Type	Valid Range	Description
SrcAddr	IEEE address	A valid 64-bit IEEE address	The source IEEE address for the binding entry.
SrcEndpoint	Integer	0x01 – 0xfe	The source endpoint for the binding entry.
ClusterId	Integer	0x0000 – 0xffff	The identifier of the cluster on the source device that is to be bound to the destination device.

Table 2.6 APSME-BIND.request Parameters (Continued)

DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddr and DstEndpoint not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddr and DstEndpoint present 0x04 – 0xff = reserved
DstAddr	Address	As specified by the DstAddrMode parameter	The destination address for the binding entry.
DstEndpoint	Integer	0x01 – 0xff	This parameter will be present only if the DstAddrMode parameter has a value of 0x03 and, if present, will be the destination endpoint for the binding entry.

2.2.4.3.1.2 When Generated

This primitive is generated by the next higher layer and issued to the APS sub-layer in order to instigate a binding operation on a device that supports a binding table.

2.2.4.3.1.3 Effect on Receipt

On receipt of this primitive by a device that is not currently joined to a network, or by a device that does not support a binding table, or if any of the parameters has a value which is out of range, the APSME issues the APSME-BIND.confirm primitive with the Status parameter set to ILLEGAL_REQUEST.

If the APS sub-layer on a device that supports a binding table receives this primitive from the NHLE, the APSME attempts to create the specified entry directly in its binding table. If the entry could be created, the APSME issues the APSME-BIND.confirm primitive with the Status parameter set to SUCCESS. If the entry could not be created due to a lack of capacity in the binding table, the APSME issues the APSME-BIND.confirm primitive with the Status parameter set to TABLE_FULL.

2.2.4.3.2 APSME-BIND.confirm

This primitive allows the next higher layer to be notified of the results of its request to bind two devices together, or to bind a device to a group.

2.2.4.3.2.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-BIND.confirm	{ Status, SrcAddr, SrcEndpoint, ClusterId, DstAddrMode, DstAddr, DstEndpoint }
--------------------	--

Table 2.7 specifies the parameters for the APSME-BIND.confirm primitive.

Table 2.7 APSME-BIND.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, ILLEGAL_REQUEST, TABLE_FULL, NOT_SUPPORTED	The results of the binding request.
SrcAddr	IEEE address	A valid 64-bit IEEE address	The source IEEE address for the binding entry.
SrcEndpoint	Integer	0x01 – 0xfe	The source endpoint for the binding entry.
ClusterId	Integer	0x0000 – 0xffff	The identifier of the cluster on the source device that is to be bound to the destination device.

Table 2.7 APSME-BIND.confirm Parameters (Continued)

DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddr and DstEndpoint not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddr and DstEndpoint present 0x04 – 0xff = reserved
DstAddr	Address	As specified by the DstAddrMode parameter	The destination address for the binding entry.
DstEndpoint	Integer	0x01 – 0xff	This parameter will be present only if the DstAddrMode parameter has a value of 0x03 and, if present, will be the destination endpoint for the binding entry.

2.2.4.3.2.2 When Generated

This primitive is generated by the APSME and issued to its NHLE in response to an APSME-BIND.request primitive. If the request was successful, the Status parameter will indicate a successful bind request. Otherwise, the Status parameter indicates an error code of NOT_SUPPORTED, ILLEGAL_REQUEST or TABLE_FULL.

2.2.4.3.2.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its bind request. If the bind request was successful, the Status parameter is set to SUCCESS. Otherwise, the Status parameter indicates the error.

2.2.4.3.3 APSME-UNBIND.request

This primitive allows the next higher layer to request to unbind two devices, or to unbind a device from a group, by removing an entry in its local binding table, if supported.

2.2.4.3.3.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-UNBIND.request	{
	SrcAddr,
	SrcEndpoint,
	ClusterId,
	DstAddrMode,
	DstAddr,
	DstEndpoint
	}

Table 2.8 specifies the parameters for the APSME-UNBIND.request primitive.

Table 2.8 APSME-UNBIND.request Parameters

Name	Type	Valid Range	Description
SrcAddr	IEEE address	A valid 64-bit IEEE address	The source IEEE address for the binding entry.
SrcEndpoint	Integer	0x01 – 0xfe	The source endpoint for the binding entry.
ClusterId	Integer	0x0000 – 0xffff	The identifier of the cluster on the source device that is bound to the destination device.
DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddr and DstEndpoint not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddr and DstEndpoint present 0x04 – 0xff = reserved
DstAddr	Address	As specified by the DstAddrMode parameter	The destination address for the binding entry.
DstEndpoint	Integer	0x01 – 0xff	This parameter will be present only if the DstAddrMode parameter has a value of 0x03 and, if present, will be the destination endpoint for the binding entry.

2.2.4.3.3.2 When Generated

This primitive is generated by the next higher layer and issued to the APS sub-layer in order to instigate an unbind operation on a device that supports a binding table.

2.2.4.3.3.3 Effect on Receipt

On receipt of this primitive by a device that is not currently joined to a network, or by a device that does not support a binding table, or if any of the parameters has a value which is out of range, the APSME issues the APSME-UNBIND.confirm primitive with the Status parameter set to ILLEGAL_REQUEST.

If the APS on a device that supports a binding table receives this primitive from the NHLE, the APSME searches for the specified entry in its binding table. If the entry exists, the APSME removes the entry and issues the APSME-UNBIND.confirm (see sub-clause 2.2.4.3.4) primitive with the Status parameter set to SUCCESS. If the entry could not be found, the APSME issues the APSME-UNBIND.confirm primitive with the Status parameter set to INVALID_BINDING.

2.2.4.3.4 APSME-UNBIND.confirm

This primitive allows the next higher layer to be notified of the results of its request to unbind two devices, or to unbind a device from a group.

2.2.4.3.4.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-UNBIND.confirm	{
	Status,
	SrcAddr,
	SrcEndpoint,
	ClusterId,
	DstAddrMode,
	DstAddr,
	DstEndpoint
	}

Table 2.9 specifies the parameters for the APSME-UNBIND.confirm primitive.

Table 2.9 APSME-UNBIND.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, ILLEGAL_REQUEST, INVALID_BINDING	The results of the unbind request.
SrcAddr	IEEE address	A valid 64-bit IEEE address	The source IEEE address for the binding entry.
SrcEndpoint	Integer	0x01 – 0xfe	The source endpoint for the binding entry.
ClusterId	Integer	0x0000 – 0xffff	The identifier of the cluster on the source device that is bound to the destination device.
DstAddrMode	Integer	0x00 – 0xff	The addressing mode for the destination address used in this primitive. This parameter can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddr and DstEndpoint not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddr and DstEndpoint present 0x04 – 0xff = reserved
DstAddr	Address	As specified by the DstAddrMode parameter	The destination address for the binding entry.
DstEndpoint	Integer	0x01 – 0xff	The destination endpoint for the binding entry.

2.2.4.3.4.2 When Generated

This primitive is generated by the APSME and issued to its NHLE in response to an APSME-UNBIND.request primitive. If the request was successful, the Status parameter will indicate a successful unbind request. Otherwise, the Status parameter indicates an error code of ILLEGAL_REQUEST, or INVALID_BINDING.

2.2.4.3.4.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its unbind request. If the unbind request was successful, the Status parameter is set to SUCCESS. Otherwise, the Status parameter indicates the error.

2.2.4.4 Information Base Maintenance

This set of primitives defines how the next higher layer of a device can read and write attributes in the AIB.

2.2.4.4.1 APSME-GET.request

This primitive allows the next higher layer to read the value of an attribute from the AIB.

2.2.4.4.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-GET.request	{
	AIBAttribute
	}

Table 2.10 specifies the parameters for this primitive.

Table 2.10 APSME-GET.request Parameters

Name	Type	Valid Range	Description
AIBAttribute	Integer	See Table 2.24	The identifier of the AIB attribute to read.

2.2.4.4.1.2 When Generated

This primitive is generated by the next higher layer and issued to its APSME in order to read an attribute from the AIB.

2.2.4.4.1.3 Effect on Receipt

On receipt of this primitive, the APSME attempts to retrieve the requested AIB attribute from its database. If the identifier of the AIB attribute is not found in the database, the APSME issues the APSME-GET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE.

If the requested AIB attribute is successfully retrieved, the APSME issues the APSME-GET.confirm primitive with a status of SUCCESS such that it contains the AIB attribute identifier and value.

2.2.4.4.2 APSME-GET.confirm

This primitive reports the results of an attempt to read the value of an attribute from the AIB.

2.2.4.4.2.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-GET.confirm	{
	Status,
	AIBAttribute,
	AIBAttributeLength,
	AIBAttributeValue
	}

Table 2.11 specifies the parameters for this primitive.

Table 2.11 APSME-GET.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS or UNSUPPORTED_ATTRIBUTE	The results of the request to read an AIB attribute value.
AIBAttribute	Integer	See Table 2.24	The identifier of the AIB attribute that was read.
AIBAttributeLength	Integer	0x0001 - 0xffff	The length, in octets, of the attribute value being returned.
AIBAttributeValue	Various	Attribute specific (see Table 2.24)	The value of the AIB attribute that was read.

2.2.4.4.2.2 When Generated

This primitive is generated by the APSME and issued to its next higher layer in response to an APSME-GET.request primitive. This primitive returns a status of SUCCESS, indicating that the request to read an AIB attribute was successful, or an error code of UNSUPPORTED_ATTRIBUTE. The reasons for these status values are fully described in sub-clause 2.2.4.4.1.3.

2.2.4.4.2.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to read an AIB attribute. If the request to read an AIB attribute was successful, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

2.2.4.4.3 APSME-SET.request

This primitive allows the next higher layer to write the value of an attribute into the AIB.

2.2.4.4.3.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-SET.request	{
	AIBAttribute,
	AIBAttributeLength,
	AIBAttributeValue
	}

Table 2.12 specifies the parameters for this primitive.

Table 2.12 APSME-SET.request Parameters

Name	Type	Valid Range	Description
AIBAttribute	Integer	See Table 2.24.	The identifier of the AIB attribute to be written.
AIBAttributeLength	Integer	0x0000 - 0xffff	The length, in octets, of the attribute value being set.
AIBAttributeValue	Various	Attribute specific (see Table 2.24).	The value of the AIB attribute that should be written.

2.2.4.4.3.2 When Generated

This primitive is to be generated by the next higher layer and issued to its APSME in order to write the value of an attribute in the AIB.

2.2.4.4.3.3 Effect on Receipt

On receipt of this primitive, the APSME attempts to write the given value to the indicated AIB attribute in its database. If the AIBAttribute parameter specifies an attribute that is not found in the database, the APSME issues the APSME-SET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE. If the AIBAttributeValue parameter specifies a value that is outside the valid range for the given attribute, the APSME issues the APSME-SET.confirm primitive with a status of INVALID_PARAMETER.

If the requested AIB attribute is successfully written, the APSME issues the APSME-SET.confirm primitive with a status of SUCCESS.

2.2.4.4.4 APSME-SET.confirm

This primitive reports the results of an attempt to write a value to an AIB attribute.

2.2.4.4.4.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-SET.confirm	{ Status, AIBAttribute }
-------------------	-----------------------------------

Table 2.13 specifies the parameters for this primitive.

Table 2.13 APSME-SET.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, INVALID_PARAMETER or UNSUPPORTED_ATTRIBUTE	The result of the request to write the AIB Attribute.
AIBAttribute	Integer	See Table 2.24.	The identifier of the AIB attribute that was written.

2.2.4.4.4.2 When Generated

This primitive is generated by the APSME and issued to its next higher layer in response to an APSME-SET.request primitive. This primitive returns a status of either SUCCESS, indicating that the requested value was written to the indicated AIB attribute, or an error code of INVALID_PARAMETER or UNSUPPORTED_ATTRIBUTE. The reasons for these status values are completely described in sub-clause 2.2.4.4.3.3.

2.2.4.4.4.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to write the value of a AIB attribute. If the requested value was written to the indicated AIB attribute, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

2.2.4.5 Group Management

This set of primitives allows the next higher layer to manage group membership for endpoints on the current device by adding and removing entries in the group table.

2.2.4.5.1 APSME-ADD-GROUP.request

This primitive allows the next higher layer to request that group membership for a particular group be added for a particular endpoint.

2.2.4.5.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

APSME-ADD-GROUP.request	{
	GroupAddress,
	Endpoint
	}

Table 2.14 specifies the parameters for this primitive.

Table 2.14 APSME-ADD-GROUP.request Parameters

Name	Type	Valid Range	Description
GroupAddress	16-bit group address	0x0000 - 0xffff	The 16-bit address of the group being added.
Endpoint	Integer	0x01 - 0xfe	The endpoint to which the given group is being added.

2.2.4.5.1.2 When Generated

This primitive is generated by the next higher layer when it wants to add membership in a particular group to an endpoint, so that frames addressed to the group will be delivered to that endpoint in the future.

2.2.4.5.1.3 Effect on Receipt

If, on receipt of this primitive, the GroupAddress parameter is found to be outside the valid range, then the APSME will issue the APSME-ADD-GROUP.confirm primitive to the next higher layer with a status value of INVALID_PARAMETER. Similarly, if the Endpoint parameter has a value which is out of range or else enumerates an endpoint that is not implemented on the current device, the APSME will issue the APSME-ADD-GROUP.confirm primitive with a Status of INVALID_PARAMETER.

After checking the parameters as described above, the APSME will check the group table to see if an entry already exists containing the values given by the GroupAddress and Endpoint parameters. If such an entry already exists in the table then the APSME will issue the APSME-ADD-GROUP.confirm primitive to the next higher layer with a status value of SUCCESS. If there is no such entry

and there is space in the table for another entry then the APSME will add a new entry to the group table with the values given by the GroupAddress and Endpoint parameters. After the entry is added to the APS group table, and if the NWK layer is maintaining a group table, then the APSME ensures that the corresponding NWK group table is consistent by issuing the NLME-SET.request primitive, for the *nwkGroupIDTable* attribute, with the list of group addresses contained in the group table of the APS sub-layer. Once both tables are consistent, the APSME issues the APSME-ADD-GROUP.confirm primitive to the next higher layer with a status value of SUCCESS. If no entry for the given GroupAddress and Endpoint is present but there is no room in the group table for another entry, then the APSME will issue the APSME-ADD-GROUP.confirm primitive to the next higher layer with a status value of TABLE_FULL.

2.2.4.5.2 APSME-ADD-GROUP.confirm

This primitive allows the next higher layer to be informed of the results of its request to add a group to an endpoint.

2.2.4.5.2.1 Semantics of the Service Primitive

The semantics of the service primitive are as follows:

APSME-ADD-GROUP.confirm	{
	Status,
	GroupAddress,
	Endpoint
	}

Table 2.15 specifies the parameters for this primitive.

Table 2.15 APSME-ADD-GROUP.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, INVALID_PARAMETER or TABLE_FULL	The status of the request to add a group.
GroupAddress	16-bit group address	0x0000 - 0xffff	The 16-bit address of the group being added.
Endpoint	Integer	0x01 - 0xfe	The endpoint to which the given group is being added.

2.2.4.5.2.2 When Generated

This primitive is generated by the APSME and issued to the next higher layer in response to an APMSE-ADD-GROUP.request primitive. If the APSME-ADD-

GROUP.request was successful, then the Status parameter value will be SUCCESS. If one of the parameters of the APMSE-ADD-GROUP.request primitive had an invalid value, then the status value will be set to INVALID_PARAMETER. If the APMSE attempted to add a group table entry but there was no room in the table for another entry, then the status value will be TABLE_FULL.

2.2.4.5.2.3 Effect on Receipt

On receipt of this primitive, the next higher layer is informed of the status of its request to add a group. The Status parameter values will be as described above.

2.2.4.5.3 APSME-REMOVE-GROUP.request

This primitive allows the next higher layer to request that group membership in a particular group for a particular endpoint be removed.

2.2.4.5.3.1 Semantics of the Service Primitive

The semantics of the service primitive are as follows:

APSME-REMOVE-GROUP.request	{
	GroupAddress,
	Endpoint
	}

Table 2.16 specifies the parameters for this primitive.

Table 2.16 APSME-REMOVE-GROUP.request Parameters

Name	Type	Valid Range	Description
GroupAddress	16-bit group address	0x0000 - 0xffff	The 16-bit address of the group being removed.
Endpoint	Integer	0x01 - 0xfe	The endpoint to which the given group is being removed.

2.2.4.5.3.2 When Generated

This primitive is generated by the next higher layer when it wants to remove membership in a particular group from an endpoint so that frames addressed to the group will no longer be delivered to that endpoint.

2.2.4.5.3.3 Effect on Receipt

If, on receipt of this primitive, the GroupAddress parameter is found to be outside the valid range, then the APSME will issue the APSME-REMOVE-

GROUP.confirm primitive to the next higher layer with a status value of INVALID_PARAMETER. Similarly, if the Endpoint parameter has a value which is out of range or else enumerates an endpoint that is not implemented on the current device, the APSME will issue the APSME-REMOVE-GROUP.confirm primitive with a Status of INVALID_PARAMETER.

After checking the parameters as described above, the APSME will check the group table to see if an entry exists containing the values given by the GroupAddress and Endpoint parameters. If such an entry already exists in the table, then that entry will be removed. If the NWK layer is maintaining a group table, then the APSME ensures that the NWK group table is consistent by issuing the NLME-SET.request primitive, for the *nwkGroupIDTable* attribute, with the list of group addresses contained in the group table of the APS sub-layer. Once both tables are consistent, the APSME issues the APSME-REMOVE-GROUP.confirm primitive to the next higher layer with a status value of SUCCESS. If there is no such entry, the APSME will issue the APSME-REMOVE-GROUP.confirm primitive to the next higher layer with a status value of INVALID_GROUP.

2.2.4.5.4 APSME-REMOVE-GROUP.confirm

This primitive allows the next higher layer to be informed of the results of its request to remove a group from an endpoint.

2.2.4.5.4.1 Semantics of the Service Primitive

The semantics of the service primitive are as follows:

APSME-REMOVE-GROUP.confirm	{
	Status,
	GroupAddress,
	Endpoint
	}

Table 2.17 specifies the parameters for this primitive.

Table 2.17 APSME-REMOVE-GROUP.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, INVALID_GROUP or INVALID_PARAMETER	The status of the request to remove a group.
GroupAddress	16-bit group address	0x0000 - 0xffff	The 16-bit address of the group being removed.
Endpoint	Integer	0x01 - 0xfe	The endpoint which is to be removed from the group.

2.2.4.5.4.2 When Generated

This primitive is generated by the APSME and issued to the next higher layer in response to an APMSE-REMOVE-GROUP.request primitive. If the APSME-REMOVE-GROUP.request was successful, the Status parameter value will be SUCCESS. If the APSME-REMOVE-GROUP.request was not successful because an entry containing the values given by the GroupAddress and Endpoint parameters did not exist, then the status value will be INVALID_GROUP. If one of the parameters of the APMSE-REMOVE-GROUP.request primitive had an invalid value, then the status value will be INVALID_PARAMETER.

2.2.4.5.4.3 Effect on Receipt

On receipt of this primitive, the next higher layer is informed of the status of its request to remove a group. The Status parameter values will be as described above.

2.2.4.5.5 APSME-REMOVE-ALL-GROUPS.request

This primitive is generated by the next higher layer when it wants to remove membership in all groups from an endpoint, so that no group-addressed frames will be delivered to that endpoint.

2.2.4.5.5.1 Semantics of the Service Primitive

The semantics of the service primitive are as follows:

APSME-REMOVE-ALL-GROUPS.request	{
	Endpoint
	}

Table 2.18 specifies the parameters for this primitive.

Table 2.18 APSME-REMOVE-ALL-GROUPS.request Parameters

Name	Type	Valid Range	Description
Endpoint	Integer	0x01 - 0xfe	The endpoint to which the given group is being removed.

2.2.4.5.5.2 When Generated

This primitive is generated by the next higher layer when it wants to remove membership in all groups from an endpoint so that no group addressed frames will be delivered to that endpoint.

2.2.4.5.5.3 Effect on Receipt

If, on receipt of this primitive, the Endpoint parameter has a value which is out of range or else enumerates an endpoint that is not implemented on the current device the APSME will issue the APSME-REMOVE-ALL-GROUPS.confirm primitive with a Status of INVALID_PARAMETER.

After checking the Endpoint parameter as described above, the APSME will remove all entries related to this endpoint from the group table. The APSME ensures that the corresponding NWK group table is consistent by issuing the NLME-SET.request primitive, for the *nwkGroupIDTable* attribute, with the list of group addresses contained in the group table of the APS sub-layer. Once both tables are consistent, the APSME issues the APSME-REMOVE-ALL-GROUPS.confirm primitive to the next higher layer with a status value of SUCCESS.

2.2.4.5.6 APSME-REMOVE-ALL-GROUPS.confirm

This primitive allows the next higher layer to be informed of the results of its request to remove all groups from an endpoint.

2.2.4.5.6.1 Semantics of the Service Primitive

The semantics of the service primitive are as follows:

APSME-REMOVE-ALL-GROUPS.confirm	{
	Status,
	Endpoint
	}

Table 2.19 specifies the parameters for this primitive.

Table 2.19 APSME-REMOVE-ALL-GROUPS.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS or INVALID_PARAMETER	The status of the request to remove all groups.
Endpoint	Integer	0x01 - 0xfe	The endpoint which is to be removed from all groups.

2.2.4.5.6.2 When Generated

This primitive is generated by the APSME and issued to the next higher layer in response to an APSME-REMOVE-ALL-GROUPS.request primitive. If the APSME-REMOVE-ALL-GROUPS.request was successful, then the Status parameter value will be SUCCESS. If the Endpoint parameter of the APSME-

REMOVE-ALL-GROUPS.request primitive had an invalid value, then the status value will be INVALID_PARAMETER.

2.2.4.5.6.3 Effect on Receipt

On receipt of this primitive, the next higher layer is informed of the status of its request to remove all groups from an endpoint. The Status parameter values will be as described above.

2.2.5 Frame Formats

This sub-clause specifies the format of the APS frame (APDU). Each APS frame consists of the following basic components:

- An APS header, which comprises frame control and addressing information.
- An APS payload, of variable length, which contains information specific to the frame type.

The frames in the APS sub-layer are described as a sequence of fields in a specific order. All frame formats in this sub-clause are depicted in the order in which they are transmitted by the NWK layer, from left to right, where the leftmost bit is transmitted first in time. Bits within each field are numbered from 0 (leftmost and least significant) to k-1 (rightmost and most significant), where the length of the field is k bits. Fields that are longer than a single octet are sent to the NWK layer in order from the octet containing the lowest-numbered bits to the octet containing the highest-numbered bits.

On transmission, all fields marked as reserved shall be set to zero. On reception, all fields marked as reserved in this version of the specification shall be checked for being equal to zero. If such a reserved field is not equal to zero, no further processing shall be applied to the frame and the frame shall be discarded.

2.2.5.1 General APDU Frame Format

The APS frame format is composed of an APS header and an APS payload. The fields of the APS header appear in a fixed order, however, the addressing fields

may not be included in all frames. The general APS frame shall be formatted as illustrated in Figure 2.2.

Octets : 1	0/1	0/2	0/2	0/2	0/1	1	0/ Variable	Variable
Frame control	Destination endpoint	Group addresses	Cluster identifier	Profile identifier	Source endpoint	APS counter	Extended header	Frame payload
	Addressing fields							
APS header								APS payload

Figure 2.2 General APS Frame Format

2.2.5.1.1 Frame Control Field

The frame control field is 8-bits in length and contains information defining the frame type, addressing fields, and other control flags. The frame control field shall be formatted as illustrated in Figure 2.3.

Bits: 0-1	2-3	4	5	6	7
Frame type	Delivery mode	Ack. format	Security	Ack. request	Extended header present

Figure 2.3 Format of the Frame Control Field

2.2.5.1.1.1 Frame Type Sub-Field

The frame type sub-field is two bits in length and shall be set to one of the non-reserved values listed in Table 2.20.

Table 2.20 Values of the Frame Type Sub-Field

Frame Type Value b ₁ b ₀	Frame Type Name
00	Data
01	Command
10	Acknowledgement
11	Reserved

2.2.5.1.1.2 Delivery Mode Sub-Field

The delivery mode sub-field is two bits in length and shall be set to one of the non-reserved values from Table 2.21.

Table 2.21 Values of the Delivery Mode Sub-Field

Delivery Mode Value $b_1 b_0$	Delivery Mode Name
00	Normal unicast delivery
01	Reserved
10	Broadcast
11	Group addressing

If the value is 0b00, the frame will be delivered to a given endpoint on the receiving device.

If the value is 0b10, the message is a broadcast. In this case, the message will go to all devices defined for the selected broadcast address in use as defined in sub-clause 3.6.5. The destination endpoint field shall be set to a value between 0x01-0xfe (for broadcasts to specific endpoints) or to 0xff (for broadcasts to all active endpoints).

If the value is 0b11, then group addressing is in use and that frame will only be delivered to device endpoints that express group membership in the group identified by the group address field in the APS header. Note that other endpoints on the source device may be members of the group addressed by the outgoing frame. The frame shall be delivered to any member of the group, including other endpoints on the source device that are members of the specified group.

Devices where *nwkUseMulticast* is set to TRUE, shall never set the delivery mode of an outgoing frame to 0b11. In this case, the delivery mode of the outgoing frame shall be set to 0b10 (broadcast) and the frame shall be sent using an NLDE-DATA.request with the destination address mode set to group addressing.

2.2.5.1.1.3 Ack Format Field

This bit indicates if the destination endpoint, cluster identifier, profile identifier and source endpoint fields shall be present in the acknowledgement frame. This is set to 0 for data frame acknowledgement and 1 for APS command frame acknowledgement.

2.2.5.1.1.4 Security Sub-Field

The Security Services Provider (see Chapter 4) manages the security sub-field.

2.2.5.1.1.5 Acknowledgement Request Sub-Field

The acknowledgement request sub-field is one bit in length and specifies whether the current transmission requires an acknowledgement frame to be sent to the originator on receipt of the frame. If this sub-field is set to 1, the recipient shall construct and send an acknowledgement frame back to the originator after determining that the frame is valid. If this sub-field is set to 0, the recipient shall not send an acknowledgement frame back to the originator.

This sub-field shall be set to 0 for all frames that are broadcast or multicast.

2.2.5.1.1.6 Extended Header Present

The extended header present sub-field is one bit in length and specifies whether the extended header shall be included in the frame. If this sub-field is set to 1, then the extended header shall be included in the frame. Otherwise, it shall not be included in the frame.

2.2.5.1.2 Destination Endpoint Field

The destination endpoint field is 8-bits in length and specifies the endpoint of the final recipient of the frame. This frame shall be included in the frame only if the delivery mode subfield is set to 0b00 (normal unicast delivery), or 0b10 (broadcast delivery). In the case of broadcast delivery, the frame shall be delivered to the destination endpoint specified within the range 0x01-0xfe or to all active endpoints if specified as 0xff.

A destination endpoint value of 0x00 addresses the frame to the ZigBee device object (ZDO), resident in each device. A destination endpoint value of 0x01-0xfe addresses the frame to an application operating on that endpoint. A destination endpoint value of 0xff addresses the frame to all active endpoints except endpoint 0x00.

2.2.5.1.3 Group Address Field

The group address field is 16 bits in length and will only be present if the delivery mode sub-field of the frame control has a value of 0b11. In this case, the destination endpoint shall not be present. If the APS header of a frame contains a group address field, the frame will be delivered to all endpoints for which the group table in the device contains an association between that endpoint and the group identified by the contents of the group address field.

Devices where *nwkUseMulticast* is set to TRUE shall never set the group address field of an outgoing frame.

2.2.5.1.4 Cluster Identifier Field

The cluster identifier field is 16 bits in length and specifies the identifier of the cluster to which the frame relates and which shall be made available for filtering

and interpretation of messages at each device that takes delivery of the frame. This field shall be present only for data or acknowledgement frames.

2.2.5.1.5 Profile Identifier Field

The profile identifier is two octets in length and specifies the ZigBee profile identifier for which the frame is intended and shall be used during the filtering of messages at each device that takes delivery of the frame. This field shall be present only for data or acknowledgement frames.

2.2.5.1.6 Source Endpoint Field

The source endpoint field is eight-bits in length and specifies the endpoint of the initial originator of the frame. A source endpoint value of 0x00 indicates that the frame originated from the ZigBee device object (ZDO) resident in each device. A source endpoint value of 0x01-0xfe indicates that the frame originated from an application operating on that endpoint.

2.2.5.1.7 APS Counter

This field is eight bits in length and is used as described in sub-clause 2.2.8.4.2 to prevent the reception of duplicate frames. This value shall be incremented by one for each new transmission.

2.2.5.1.8 Extended Header Sub-Frame

The extended header sub-frame contains further sub-fields and shall be formatted as illustrated in Figure 2.4.

Octets: 1	0/1	0/1
Extended frame control	Block number	ACK bitfield

Figure 2.4 Format of the Extended Header Sub-Frame

2.2.5.1.8.1 Extended Frame Control Field

The extended frame control field is eight-bits in length and contains information defining the use of fragmentation. The extended frame control field shall be formatted as illustrated in Figure 2.5.

Bits: 0-1	2-7
Fragmentation	Reserved

Figure 2.5 Format of the Extended Frame Control Field

The fragmentation sub-field is two bits in length and shall be set to one of the non-reserved values listed in Table 2.22.

Table 2.22 Values of the Fragmentation Sub-Field

Fragmentation Value b ₁ b ₀	Description
00	Transmission is not fragmented.
01	Frame is first fragment of a fragmented transmission.
10	Frame is part of a fragmented transmission but not the first part.
11	Reserved

2.2.5.1.8.2 Block Number

The block number field is one octet in length and is used for fragmentation control as follows: If the fragmentation sub-field is set to indicate that the transmission is not fragmented then the block number field shall not be included in the sub-frame. If the fragmentation sub-field is set to 01, then the block number field shall be included in the sub-frame and shall indicate the number of blocks in the fragmented transmission. If the fragmentation sub-field is set to 10, then the block number field shall be included in the sub-frame and shall indicate which block number of the transmission the current frame represents, taking the value 0x01 for the second fragment, 0x02 for the third, etc.

2.2.5.1.8.3 Ack Bitfield

The ack bitfield field is one octet in length and is used in an APS acknowledgement as described in sub-clause 2.2.8.4.5.2 to indicate which blocks of a fragmented ASDU have been successfully received. This field is only present if the frame type sub-field indicates an acknowledgement and the fragmentation sub-field indicates a fragmented transmission.

2.2.5.1.9 Frame Payload Field

The frame payload field has a variable length and contains information specific to individual frame types.

2.2.5.2 Format of Individual Frame Types

There are three defined frame types: data, APS command, and acknowledgement. Each of these frame types is discussed in the following sub-clauses.

2.2.5.2.1 Data Frame Format

The data frame shall be formatted as illustrated in Figure 2.6.

Octets : 1	0/1	0/2	2	2	1	1	0/ Variable	Variable
Frame control	Destination endpoint	Group address	Cluster identifier	Profile Identifier	Source endpoint	APS counter	Extended header	Frame payload
Addressing fields								
APS header								APS payload

Figure 2.6 Data Frame Format

The order of the fields of the data frame shall conform to the order of the general APS frame as illustrated in Figure 2.2.

2.2.5.2.1.1 Data Frame APS Header Fields

The APS header field for a data frame shall contain the frame control, cluster identifier, profile identifier, source endpoint and APS counter fields. The destination endpoint, group address and extended header fields shall be included in a data frame according to the values of the delivery mode and extended header present sub-fields of the frame control field.

In the frame control field, the frame type sub-field shall contain the value that indicates a data frame, as shown in Table 2.20. All other sub-fields shall be set appropriately according to the intended use of the data frame.

2.2.5.2.1.2 Data Payload Field

For an outgoing data frame, the data payload field shall contain part or all of the sequence of octets that the next higher layer has requested the APS data service to transmit. For an incoming data frame, the data payload field shall contain all or part of the sequence of octets that has been received by the APS data service and that is to be delivered to the next higher layer.

2.2.5.2.2 APS Command Frame Format

The APS command frame shall be formatted as illustrated in Figure 2.7.

Octets: 1	1	1	Variable
Frame control	APS counter	APS command identifier	APS command payload
APS header		APS payload	

Figure 2.7 APS Command Frame Format

The order of the fields of the APS command frame shall conform to the order of the general APS frame as illustrated in Figure 2.2.

2.2.5.2.2.1 APS Command Frame APS Header Fields

The APS header field for an APS command frame shall contain the frame control and APS counter fields. In this version of the specification, the APS command frame shall not be fragmented and the extended header field shall not be present.

In the frame control field, the frame type sub-field shall contain the value that indicates an APS command frame, as shown in Table 2.20. The APS Command Payload shall be set appropriately according to the intended use of the APS command frame.

2.2.5.2.2.2 APS Command Identifier Field

The APS command identifier field identifies the APS command being used.

2.2.5.2.2.3 APS Command Payload Field

The APS command payload field of an APS command frame shall contain the APS command itself.

2.2.5.2.3 Acknowledgement Frame Format

The acknowledgement frame shall be formatted as illustrated in Figure 2.8.

Octets: 1	0/1	0/2	0/2	0/1	1	0/ Variable
Frame control	Destination endpoint	Cluster identifier	Profile identifier	Source endpoint	APS counter	Extended header
APS header						

Figure 2.8 Acknowledgement Frame Format

The order of the fields of the acknowledgement frame shall conform to the order of the general APS frame as illustrated in Figure 2.2.

2.2.5.2.3.1 Acknowledgement Frame APS Header Fields

If the ack format field is not set in the frame control field, the destination endpoint, cluster identifier, profile identifier and source endpoint shall be present. This is not set for data frame acknowledgement. The extended header field shall be included in a data frame according to the value of the extended header present sub-field of the frame control field.

In the frame control field, the frame type sub-field shall contain the value that indicates an acknowledgement frame, as shown in Table 2.20. The extended header present sub-field shall contain the same value as in the frame to which this frame is an acknowledgement. All other sub-fields shall be set appropriately according to the intended use of the acknowledgement frame.

If the ack format field is set in the frame control field, the frame is an APS command frame acknowledgement and the destination endpoint, cluster identifier, profile identifier and source endpoint fields shall not be included. Alternatively, if an APS data frame is being acknowledged, the source endpoint field shall reflect the value in the destination endpoint field of the frame that is being acknowledged. Similarly, the destination endpoint field shall reflect the value in the source endpoint field of the frame that is being acknowledged. And the Cluster identifier and Profile identifier fields shall contain the same values as in the frame to which this frame is an acknowledgement.

The APS counter field shall contain the same value as the frame to which this frame is an acknowledgment.

Where the extended header is present, the fragmentation sub-field of the extended frame control field shall contain the same value as in the frame to which this frame is an acknowledgement. If fragmentation is in use for this frame, then the block number and ack bitfield fields shall be present. Where present, the block number field shall contain block number to which this frame is an acknowledgement. If fragmentation is in use, the acknowledgement frames shall be issued according to sub-clause 2.2.8.4.5.2 and not for each received frame unless the transmission window size is set to request acknowledgement of each frame.

2.2.6 Command Frames

This specification defines no command frames. Refer to sub-clause 4.4.9 for a thorough description of the APS command frames and primitives related to security.

2.2.7 Constants and PIB Attributes

2.2.7.1 APS Constants

The constants that define the characteristics of the APS sub-layer are presented in Table 2.23.

Table 2.23 APS Sub-Layer Constants

Constant	Description	Value
<i>apscMaxDescriptorSize</i>	The maximum number of octets contained in a non-complex descriptor.	64
<i>apscMaxFrameRetries</i>	The maximum number of retries allowed after a transmission failure.	3
<i>apscAckWaitDuration</i>	The maximum number of seconds to wait for an acknowledgement to a transmitted frame.	0.05 * (2* <i>nwkcMaxDepth</i>) + (security encrypt/ decrypt delay), where the (security encrypt/ decrypt delay) = 0.1 (assume 0.05 per encrypt or decrypt cycle)
<i>apscMinDuplicateRejecti onTableSize</i>	The minimum required size of the APS duplicate rejection table.	1
<i>apscMinHeaderOverhead</i>	The minimum number of octets added by the APS sub-layer to an ASDU.	0x0C

2.2.7.2 APS Information Base

The APS information base comprises the attributes required to manage the APS layer of a device. The attributes of the AIB are listed in Table 2.24. The security-related AIB attributes are described in sub-clause 4.4.10.

Table 2.24 APS IB Attributes

Attribute	Identifier	Type	Range	Description	Default
<i>apsBindingTable</i>	0xc1	Set	Variable	The current set of binding table entries in the device (see sub-clause 2.2.8.2.1).	Null set
<i>apsDesignatedCoordinator</i>	0xc2	Boolean	TRUE or FALSE	TRUE if the device should become the ZigBee Coordinator on startup, FALSE if otherwise.	FALSE
<i>apsChannelMask</i>	0xc3	IEEE802.15.4 channel mask	Any legal mask for the PHY	The mask of allowable channels for this device to use for network operations.	All channels
<i>apsUseExtendedPANID</i>	0xc4	64-bit extended address	0x00000000 to 0xffffffffffffe	The 64-bit address of a network to form or to join.	0x0000000000000000
<i>apsGroupTable</i>	0xc5	Set	Variable	The current set of group table entries (see Table 2.25).	Null set
<i>apsNonmemberRadius</i>	0xc6	Integer	0x00-0x07	The value to be used for the NonmemberRadius parameter when using NWK layer multicast.	2
<i>apsPermissionsConfiguration</i>	0xc7	See Table 2.23	Variable	The current set of permission configuration items.	Null set
<i>apsUseInsecureJoin</i>	0xc8	Boolean	TRUE or FALSE	A flag controlling the use of insecure join at startup.	TRUE
<i>apsInterframeDelay</i>	0xc9	Integer	0x00 to 0xff (may be restricted by application profile)	Fragmentation parameter - the standard delay, in milliseconds, between sending two blocks of a fragmented transmission (see sub-clause 2.2.8.4.5).	Set by application profile

Table 2.24 APS IB Attributes (Continued)

<i>apsLastChannelEnergy</i>	0xca	Integer	0x00 - 0xff	The energy measurement for the channel energy scan performed on the previous channel just before a channel change (in accordance with [B1]).	Null set
<i>apsLastChannelFailureRate</i>	0xcb	Integer	0-100 (decimal)	The latest percentage of transmission network transmission failures for the previous channel just before a channel change (in percentage of failed transmissions to the total number of transmissions attempted)	Null set
<i>apsChannelTimer</i>	0xcc	Integer	1-24 (decimal)	A countdown timer (in hours) indicating the time to the next permitted frequency agility channel change. A value of NULL indicates the channel has not been changed previously.	Null set
<i>apsMaxWindowSize</i>	0xcd	See Table 2.26	Variable	A table with the active endpoints and their respective <i>apsMaxWindowSize</i> where fragmentation is used (active endpoints not supporting fragmentations shall be omitted from the list)	Null set

Table 2.25 Group Table Entry Format

Group ID	Endpoint List
16-bit group address	List of endpoints on this device which are members of the group.

Table 2.26 *apsMaxWindowSize* by Endpoint Number

Endpoint Number	<i>apsMaxWindowSize</i> for the Endpoint Number
0x01 - 0xff	Value of 1-8

2.2.8 Functional Description

2.2.8.1 Persistent Data

The APS is required to maintain a minimum set of data in persistent memory. This data set shall persist over power fail, device reset, or other processing events. The following data shall be maintained in persistent memory within APS:

- *apsBindingTable* (if supported on the device)
- *apsDesignatedCoordinator* (if supported on the device)
- *apsChannelMask*
- *apsUseExtendedPANID*
- *apsUseInsecureJoin*
- *apsGroupTable* (if supported on the device)
- Binding Table Cache (if the device is designated as a primary or backup binding table cache, see clause 2.4.2.4)
- Discovery Cache (if the device is designated as a primary discovery cache, see clause 2.4.2.1)
- Node Descriptor, Power Descriptor plus the Simple Descriptor(s) for each active endpoint on the device
- Network manager address

The method by which these data are made to persist is beyond the scope of this specification.

2.2.8.2 Binding

The APS may maintain a binding table, which allows ZigBee devices to establish a designated destination for frames from a given source endpoint and with a given cluster ID. Each designated destination shall represent either a specific endpoint on a specific device, or a group address.

2.2.8.2.1 Binding Table Implementation

A device designated as containing a binding table shall be able to support a binding table of implementation-specific length. The binding table shall implement the following mapping:

$$(a_s, e_s, c_s) = \{(a_{d1}, e_{d1}), (a_{d2}, e_{d2}) \dots (a_{dn}, e_{dn})\}$$

Where:

a_s	= the address of the device as the source of the binding link.
e_s	= the endpoint identifier of the device as the source of the binding link.
c_s	= the cluster identifier used in the binding link.
a_{di}	= the i^{th} destination address or destination group address associated with the binding link.
e_{di}	= the i^{th} optional destination endpoint identifier associated with the binding link. Note that e_{di} will only be present when a_{di} is a device address.

2.2.8.2.2 Binding

The APSME-BIND.request or APSME-UNBIND.request primitives initiate the procedure for creating or removing a binding link. Only a device supporting a binding table cache, or a device that wishes to store source bindings, shall initiate this procedure. If this procedure is initiated by another type of device, then the APSME shall issue the APSME-BIND.confirm or APSME-UNBIND.confirm primitive with the Status parameter set to ILLEGAL_REQUEST.

When this procedure is initiated, the APSME shall first extract the address and endpoint for both the source and destination of the binding link. If the DstAddrMode parameter has a value of 0x01, indicating group addressing, then only the source address is treated in the way just described. The 16-bit group address is used directly as a destination address and, in this case, no destination endpoint is specified. With this information, the APSME shall either create a new entry or remove the corresponding entry from its binding table, depending on whether the bind or unbind procedure, respectively, was initiated.

If a bind operation was requested, the APSME shall create a new entry in the binding table. The device shall only create a new entry in the binding table if it has the capacity to do so. If the binding table does not have capacity, then the APSME shall issue the APSME-BIND.confirm primitive with the Status parameter set to TABLE_FULL.

If an unbind operation was requested, the APSME shall search the binding table for an existing entry that matches the information contained in the initiation request. If an entry is not found, the APSME shall terminate the procedure and notify the NHLE of the invalid binding. This is achieved by issuing the APSME-

UNBIND.confirm primitive with the Status parameter set to INVALID_BINDING. If an entry is found, the APSME shall remove the entry in the binding table.

If the binding link is successfully created or removed, the APSME shall notify the NHLE of the results of the binding attempt and the success of the procedure. This is achieved by issuing the APSME-BIND.confirm or APSME-UNBIND.confirm primitive, respectively, with the binding results and the Status parameter set to SUCCESS.

The procedure for a successful binding is illustrated in the MSC shown in Figure 2.9.

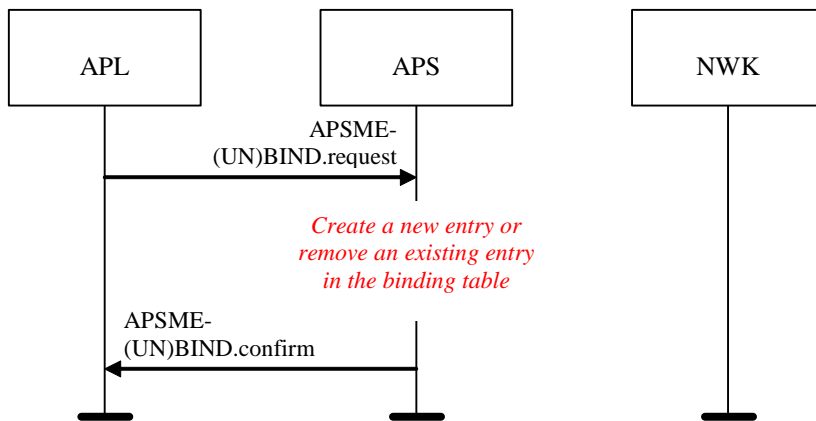


Figure 2.9 Binding on a Device Supporting a Binding Table

2.2.8.3 Group Addressing

The APS sub-layer shall maintain a group table, which allows endpoints to be associated with groups and allows group-addressed frames to be delivered selectively to those endpoints that are associated in the table with a particular group.

The list of group addresses in the APS sub-layer group table shall be kept consistent with the list of group IDs in the NWK layer group table, stored in the *nwkGroupIDTable* attribute.

2.2.8.3.1 The Group Table

For purposes of this discussion, the group table shall be viewed as a set of associations between groups and endpoints as follows:

$$\{(g_1 - ep_{11}, ep_{12} \dots ep_{1n}), (g_2 - ep_{21}, ep_{22} \dots ep_{2m}) \dots (g_i - ep_{i1}, ep_{i2} \dots ep_{ik})\}$$

where:

g_i	=	the i^{th} group represented in the table.
ep_{ij}	=	the j^{th} endpoint associated with the i^{th} group.

Implementers of this specification are free to implement the group table in any manner that is convenient and efficient, as long as it represents the associations just described.

2.2.8.4 **Transmission, Reception, and Acknowledgement**

This sub-clause describes the fundamental procedures for transmission, reception, and acknowledgement.

2.2.8.4.1 **Transmission**

Only those devices that are currently part of a network shall send frames from the APS sub-layer. If any other device receives a request to transmit a frame, it shall discard the frame and notify the instigating layer of the error. An APSDE-DATA.confirm primitive with a status of CHANNEL_ACCESS_FAILURE indicates that the attempt at transmission of the frame was unsuccessful due to the channel being busy.

All frames handled by or generated within the APS sub-layer shall be constructed according to the general frame format specified in sub-clause 2.2.5.1 and transmitted using the NWK layer data service.

Transmissions employing delivery modes 0b00 (Normal Unicast) and 0b10 (Broadcast) shall include both the source endpoint and destination endpoint fields. Group addressed transmissions, having a delivery mode sub-field value of 0b11 shall contain a source endpoint field and group address field, but no destination endpoint field. Note that other endpoints on the source device are legal group members and possible destinations for group-addressed frames.

For all devices where the transmission is due to a binding table entry stored on the source device, the APSDE of the source device shall determine whether the binding table entry contains a unicast destination device address or a destination group address. In the case where a binding table entry contains a unicast destination device address and this destination device address is that of the source device itself, the APSDE shall issue an APSDE-DATA.indication primitive to the next higher layer and shall not transmit a frame. Otherwise, the APSDE shall transmit the frame to the 16-bit NWK address corresponding to the destination address indicated by the binding table entry, and the delivery mode sub-field of the frame control field shall be set to 0b00. In the case where the binding table entry contains a destination group address and *nwkUseMulticast* is FALSE, the delivery mode sub-field of the frame control field shall have a value of 0b11, the destination group address shall be placed in the APS header, and the destination

endpoint shall be omitted. The frame shall then be broadcast using the NLDE-DATA.request primitive and employing a broadcast address of 0xffffd. In the case where the binding table entry contains a destination group address and *nwkUseMulticast* is TRUE, the delivery mode sub-field of the frame control field shall have a value of 0b10 and the destination endpoint shall have a value of 0xff. The frame shall then be multicast using the NLDE-DATA.request primitive and employing the group address supplied in the binding table entry.

If security is required, the frame shall be processed as described in clause 4.4.

If fragmentation is required, and is permitted for this frame, then the frame shall be processed as described in clause 2.2.8.4.5.

When the frame is constructed and ready for transmission, it shall be passed to the NWK data service with suitable destination and source addresses. In addition, the APS layer shall ensure that route discovery is enabled at the network layer. An APDU transmission is initiated by issuing the NLDE-DATA.request primitive to the NWK layer and the results of the transmission returned via the NLDE-DATA.confirm primitive.

2.2.8.4.2 Reception and Rejection

The APS sub-layer shall be able to filter frames arriving via the NWK layer data service and only present the frames that are of interest to the NHLE.

If the APSDE receives a secured frame, it shall process the frame as described in clause 4.4 to remove the security.

If the APSDE receives a frame containing the destination endpoint field, then the APSDE shall pass it directly to the NHLE at the destination endpoint supplied, unless it is part of an incomplete fragmented transmission or it is determined to have been a duplicate of a frame that has been passed up previously. Subject to the same incomplete fragmented transmission and duplicate frame detection, if the destination endpoint is set to the broadcast endpoint (0xff) and the *DstAddrMode* parameter of the received NLDE-DATA.indication primitive was not 0x01, then the APSDE shall also present the frame to all non-reserved endpoints (0x01-0xfe) supported by the NHLE.

If the APSDE of a device receives a transmission with the delivery mode sub-field of the frame control field set to 0b11, indicating group addressing, it shall deliver the frame to each endpoint on the device that is associated in the group table with the 16-bit group address found in the group address field of the APS header. Similarly, if the APSDE of a device receives a NLDE-DATA.indication primitive where the *DstAddrMode* parameter has a value of 0x01, also indicating group addressing, it shall deliver the frame to each endpoint on the device that is associated in the group table with the 16-bit group address given as the value of the *DstAddr* parameter. In either case, it shall search the group table and, for each endpoint associated with the given group address, it shall issue the NLDE-

DATA.indication primitive to the next higher layer with a value of the DstEndpoint parameter equal to the number of the associated endpoint. All other parameters of the NLDE-DATA.indication primitive shall remain the same for all instances of the primitive issued.

The APSDE shall maintain a duplicate rejection table to include at least source address, APS counter, and timing information, such that frames transmitted according to this specification and received more than once are identified as duplicates and only delivered to the NHLE once. The size of this table shall be at least *apscMinDuplicateRejectionTableSize*.

2.2.8.4.3 Use of Acknowledgements

A data or APS command frame shall be sent with its acknowledgement request sub-field set appropriately for the frame. An acknowledgement frame shall always be sent with the acknowledgement request sub-field set to 0. Similarly, any frame that is broadcast or multicast shall be sent with its acknowledgement request sub-field set to 0.

2.2.8.4.3.1 No Acknowledgement

A frame that is received by its intended recipient with its acknowledgement request (AR) sub-field set to 0 shall not be acknowledged. The originating device shall assume that the transmission of the frame was successful. Figure 2.10 shows the scenario for transmitting a single frame of data from an originator to a recipient without requiring an acknowledgement. In this case, the originator transmits the data frame with the AR sub-field equal to 0.

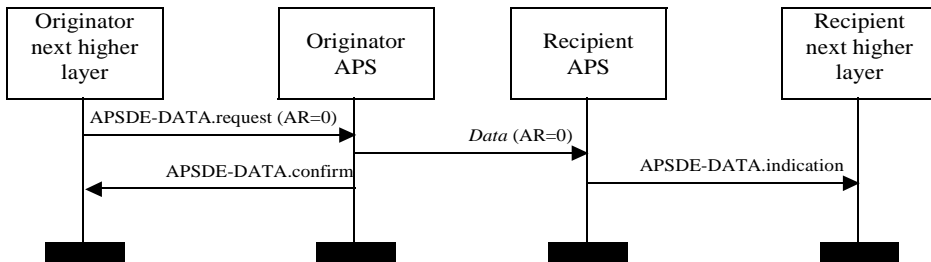


Figure 2.10 Successful Data Transmission Without an Acknowledgement

2.2.8.4.3.2 Acknowledgement

A frame that is received by its intended recipient with its acknowledgement request (AR) sub-field set to 1 shall be acknowledged. If the intended recipient correctly receives the frame, it shall generate and send an acknowledgement frame to the originator of the frame that is being acknowledged.

The transmission of an acknowledgement frame shall commence when the APS sub-layer determines that the frame is valid.

Figure 2.11 shows the scenario for transmitting a single frame of data from an originator to a recipient with an acknowledgement. In this case, the originator indicates to the recipient that it requires an acknowledgement by transmitting the data frame with the AR sub-field set to 1.

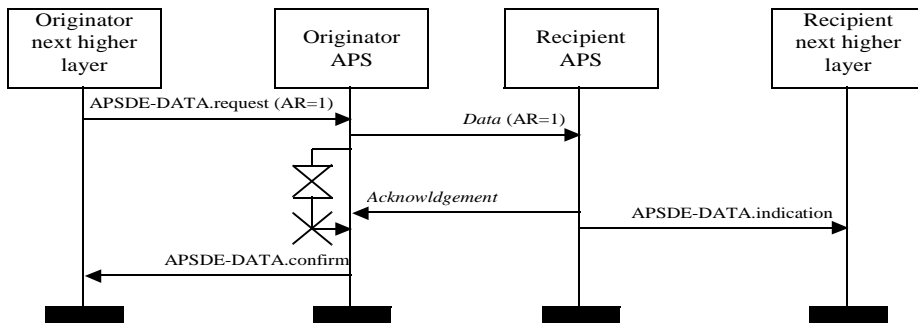


Figure 2.11 Successful Data Transmission With an Acknowledgement

2.2.8.4.4 Retransmissions

A device that sends a frame with its acknowledgement request sub-field set to 0 shall assume that the transmission was successfully received and shall hence not perform the retransmission procedure.

A device that sends a frame with its acknowledgement request sub-field set to 1 shall wait for a maximum of *apscAckWaitDuration* seconds for the corresponding acknowledgement frame to be received.

If an acknowledgement frame is received within *apscAckWaitDuration* seconds, containing the same cluster identifier and APS counter as the original frame and has a source endpoint equal to the destination endpoint to which the original frame was transmitted, the transmission shall be considered successful and no further action shall be taken by the device. If an acknowledgement is not received within *apscAckWaitDuration* seconds, or an acknowledgement is received within *apscAckWaitDuration* seconds but contains an unexpected cluster identifier or APS counter or has a source endpoint that is not equal to the destination endpoint to which the original frame was transmitted, the device shall conclude that the single transmission attempt has failed.

If a single transmission attempt has failed, the device shall repeat the process of transmitting the frame and waiting for the acknowledgement, up to a maximum of *apscMaxFrameRetries* times. If an acknowledgement is still not received after

apscMaxFrameRetries retransmissions, the APS sub-layer shall assume the transmission has failed and notify the next higher layer of the failure.

Retransmissions of a secured frame shall use a frame counter greater than the original frame.

2.2.8.4.5 Fragmented Transmissions

Where an ASDU is too large to be transmitted within a single MAC data frame, an acknowledged unicast transmission was requested, and fragmentation is permitted for this frame, the ASDU shall be fragmented into a number of smaller byte strings, here referred to as “blocks.” Each block is transmitted in a separate frame.

A “transmission window” is used to arrange an orderly transaction. The window size is set by the stack profile, and may be set as high as eight blocks. The protocol below arranges that all blocks in a transmission window must be received and acknowledged before the window can move on. An acknowledgement is sent when all blocks in the transmission window have been successfully received or, according to the protocol below, to request retransmission of one or more unreceived blocks.

Transactions not using APS acknowledgements may not be fragmented. Multicast and broadcast transmissions are not permitted to use fragmentation.

2.2.8.4.5.1 Transmission

All blocks in a fragmented transmission shall have the same APS Counter value. The extended header sub-frame shall be included in the frame. The fragmentation sub-field of the extended frame control field shall be set to 0b01 for the first block and 0b10 for all subsequent blocks of the a fragmented transmission. The block number field shall indicate the total number of blocks in the transmission in the first block, shall take the value 0x01 in the second block, and thereafter shall be incremented for each subsequent block.

A transmission window shall be maintained, initially covering blocks 0 to (*apscMaxWindowSize-1*), or the total number of blocks if this is less.

If security is required, then each frame shall be processed independently, as described in clause 4. Following transmission of each block, the APS shall start a timer. If there are more unacknowledged blocks to send in the current transmission window, then after a delay of *apscInterframeDelay* milliseconds the next block shall be passed to the NWK data service. Otherwise, the timer shall be set for *apscAckWaitDuration* seconds.

A retryCounter parameter shall be maintained and is reset to zero for each new transaction. If an *apscAckWaitDuration* timer expires, then the block with the lowest unacknowledged block number shall be passed to the NWK data service again, and the retryCounter parameter shall be incremented. If the retryCounter parameter reaches the value *apscMaxFrameRetries*, the transaction shall be

deemed to have failed, and an APSDE-DATA.confirm primitive returned to the NHLE with a status value of NO_ACK.

On receipt of an acknowledgement frame with matching values in the APS counter, block number, and addressing fields, outgoing blocks are acknowledged as described in the section below. If at least one previously unacknowledged block is acknowledged, then the timer shall be stopped and the retryCounter parameter reset. If all blocks in the current transmission window have been acknowledged, then the transmission window shall be increased by *apscMaxWindowSize*. If all blocks have now been transmitted and acknowledged, then the transaction is complete, and an APSDE-DATA.confirm primitive shall be returned to the NHLE with a status value of SUCCESS. Otherwise, the block with the lowest unacknowledged block number shall be passed to the NWK data service.

2.2.8.4.5.2 Reception and Rejection, and Acknowledgements

If the fields required for a fragmentation-enabled transmission are not present in the frame it shall be rejected. Also, any frames with parameters that fall outside the bounds of this protocol shall be rejected.

If an incoming fragmented transaction is already in progress but the addressing and APS counter fields do not match those of the received frame, then the received frame may optionally be rejected or handled independently as a further transaction.

If no transaction is in progress and a fragmented frame is received, then reassembly shall be attempted. Initially the receive window shall be from 0 to (*apscMaxWindowSize-1*).

If a transaction is initiated with APS counter and source address field values matching a previously received transaction, then the new transaction may be rejected as a duplicate.

Upon receipt of the first received block (not necessarily block 0) in the first window, or when an acknowledgement is generated, the receiver shall set a timer for *apscAckWaitDuration*.⁸

If the receive window does not move forward within any (*apscAckWaitDuration* + *apscAckWaitDuration* * *apscMaxFrameRetries*) time period, the transaction shall be deemed to have failed. The receiver may send an acknowledgement to the sender with the block or blocks missed.

If all blocks in the current receive window have been received and a block is received with a block number higher than the current receive window, then the receive window shall be increased by *apsMaxWindowSize* blocks.

8. CCB 1329

Additionally an APS acknowledgement shall be generated for the window if any one of the following circumstances occurs: (1) the last block in the entire fragmented transmission is received, (2) the last block in the window is received, (3) a block is received and all subsequent blocks in the window have been previously received and acknowledged. If a block is received with its block number value outside of the current window, then an acknowledgement shall NOT be generated.⁹

Once all blocks in the transaction have been received, the APS shall issue an APSDE-DATA.indication primitive containing the reassembled message, and the transaction shall be deemed to be complete. A period of persistence of *apscAckWaitDuration* seconds is encouraged in order to facilitate any retransmission of the final acknowledgement.

Where generated, the acknowledgement is formatted according to the acknowledgement frame format specified in sub-clause 2.2.5.2.3. The APS counter field shall reflect the value in the corresponding field of the frame(s) being acknowledged. The block number field shall contain the value of the lowest block number in the current receive window, using the value 0 as the value of the first block.

The first bit of the ack bitfield shall be set to 1 if the first fragment in the current receive window has been correctly received, and 0 otherwise. Subsequent bits shall be set similarly, with values corresponding to subsequent fragments in the current receive window. If *apscMaxWindowSize* is less than 8, then the remaining bits shall be set to 1.

The process is illustrated in the following diagrams. In Figure 2.12, the transmission is successful immediately. (These examples assume that *apscMaxWindowSize* takes the value 3).

9. CCB 1328

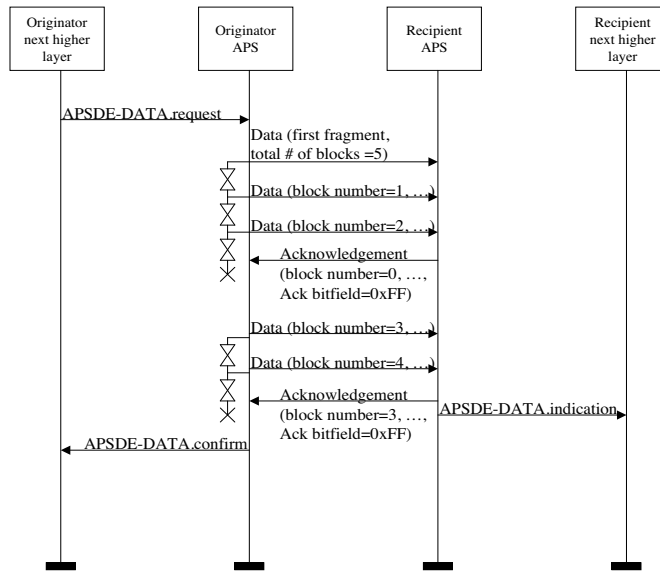


Figure 2.12 Successful Data Transmission with Fragmentation

In Figure 2.13, a single frame is lost during transit across the network, and is retransmitted.

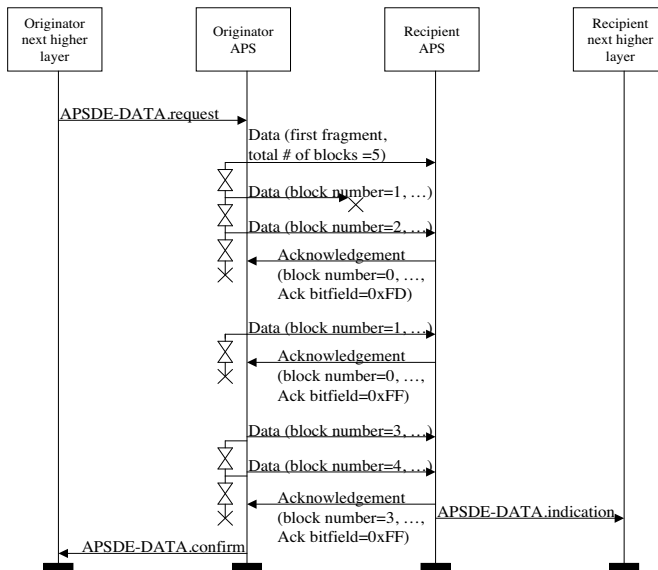


Figure 2.13 Fragmented Data Transmission with a Single Retransmission

In Figure 2.14, multiple frames are lost in the network, including a frame which has the highest block number in the window. Slightly more traffic is required in this case, but the source backs off and gives the network a chance to recover, and the ASDU is delivered successfully.

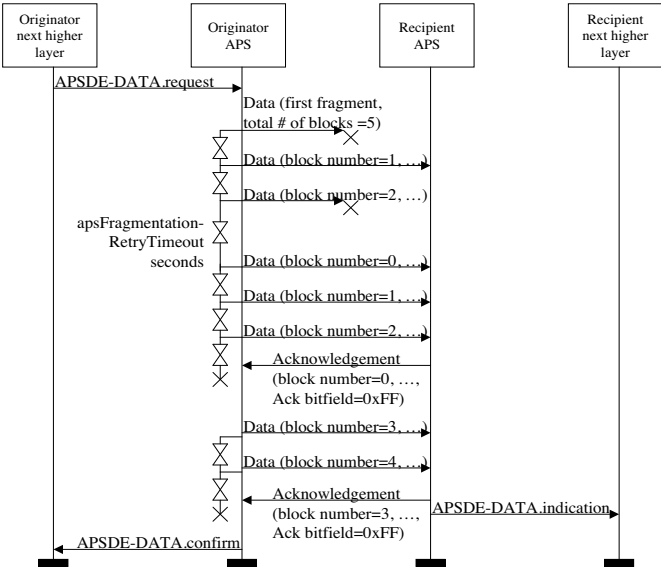


Figure 2.14 Fragmented Data Transmission with Multiple Retransmissions

2.2.9 APS Sub-Layer Status Values

Application support (APS) sub-layer confirm primitives often include a parameter that reports on the status of the request to which the confirmation applies. Values for APS sub-layer Status parameters appear in Table 2.27.

Table 2.27 APS Sub-layer Status Values

Name	Value	Description
SUCCESS	0x00	A request has been executed successfully.
ASDU_TOO_LONG	0xa0	A transmit request failed since the ASDU is too large and fragmentation is not supported.
DEFRAG_DEFERRED	0xa1	A received fragmented frame could not be defragmented at the current time.
DEFRAG_UNSUPPORTED	0xa2	A received fragmented frame could not be defragmented since the device does not support fragmentation.
ILLEGAL_REQUEST	0xa3	A parameter value was out of range.

Table 2.27 APS Sub-layer Status Values (Continued)

Name	Value	Description
INVALID_BINDING	0xa4	An APSME-UNBIND.request failed due to the requested binding link not existing in the binding table.
INVALID_GROUP	0xa5	An APSME-REMOVE-GROUP.request has been issued with a group identifier that does not appear in the group table.
INVALID_PARAMETER	0xa6	A parameter value was invalid or out of range.
NO_ACK	0xa7	An APSDE-DATA.request requesting acknowledged transmission failed due to no acknowledgement being received.
NO_BOUND_DEVICE	0xa8	An APSDE-DATA.request with a destination addressing mode set to 0x00 failed due to there being no devices bound to this device.
NO_SHORT_ADDRESS	0xa9	An APSDE-DATA.request with a destination addressing mode set to 0x03 failed due to no corresponding short address found in the address map table.
NOT_SUPPORTED	0xaa	An APSDE-DATA.request with a destination addressing mode set to 0x00 failed due to a binding table not being supported on the device.
SECURED_LINK_KEY	0xab	An ASDU was received that was secured using a link key.
SECURED_NWK_KEY	0xac	An ASDU was received that was secured using a network key.
SECURITY_FAIL	0xad	An APSDE-DATA.request requesting security has resulted in an error during the corresponding security processing.
TABLE_FULL	0xae	An APSME-BIND.request or APSME.ADD-GROUP.request issued when the binding or group tables, respectively, were full.
UNSECURED	0xaf	An ASDU was received without any security.
UNSUPPORTED_ATTRIBUTE	0xb0	An APSME-GET.request or APSME-SET.request has been issued with an unknown attribute identifier.

2.3 The ZigBee Application Framework

2.3.1 Creating a ZigBee Profile

The key to communicating between devices on a ZigBee network is agreement on a profile.

An example of a profile would be home automation. This ZigBee profile permits a series of device types to exchange control messages to form a wireless home automation application. These devices are designed to exchange well-known messages to effect control such as turning a lamp on or off, sending a light sensor measurement to a lighting controller, or sending an alert message if an occupancy sensor detects movement.

An example of another type of profile is the device profile that defines common actions between ZigBee devices. To illustrate, wireless networks rely on the ability for autonomous devices to join a network and discover other devices and services on devices within the network. Device and service discovery are features supported within the device profile.

2.3.1.1 Getting a Profile Identifier from the ZigBee Alliance

ZigBee defines profiles in two separate classes: manufacturer-specific and public. The exact definition and criteria for these classes are an administrative issue within the ZigBee Alliance and outside the scope of this document. For the purposes of this technical specification, the only criterion is for profile identifiers to be unique. To that end, every profile effort must start with a request to the ZigBee Alliance for allocation of a profile identifier. Once the profile identifier is obtained, that profile identifier permits the profile designer to define the following:

- Device descriptions
- Cluster identifiers

The application of profile identifiers to market space is a key criterion for issuance of a profile identifier from the ZigBee Alliance. The profile needs to cover a broad enough range of devices to permit interoperability to occur between devices, without being overly broad and resulting in a shortage of cluster identifiers to describe their interfaces. Conversely, the profile cannot be defined to be too narrowly, resulting in many devices described by individual profile identifiers, resulting in a waste of the profile identifier addressing space and interoperability issues in describing how the devices are interfaced. Policy groups within the ZigBee Alliance will establish criteria on how profiles are to be defined and to help requestors tailor their profile identifier requests.

2.3.1.2 Defining Device Descriptions and Clusters

The profile identifier is the main enumeration feature within the ZigBee protocol. Each unique profile identifier defines an associated enumeration of device descriptions and cluster identifiers. For example, for profile identifier “1”, there exists a pool of device descriptions described by a 16-bit value (meaning there are 65,536 possible device descriptions within each profile) and a pool of cluster identifiers described by a 16-bit value (meaning there are 65,536 possible cluster identifiers within each profile). Each cluster identifier also supports a pool of attributes described by a 16-bit value. As such, each profile identifier has up to 65,536 cluster identifiers and each of those cluster identifiers contains up to 65,536 attributes. It is the responsibility of the profile developer to define and allocate device descriptions, cluster identifiers, and attributes within their allocated profile identifier. Note that the definition of device descriptions, cluster identifiers, and attribute identifiers must be undertaken with care to ensure efficient creation of simple descriptors and simplified processing when exchanging messages.

For public profile identifiers defined within the ZigBee Alliance, a cluster library has been created which provides a common definition and enumeration of clusters and their attributes. The cluster library is designed to sponsor re-use of cluster and attribute definitions across application profiles. By convention, when public profiles employ the cluster library, they will share a common enumeration and definition of cluster and attribute identifiers.

Device descriptions and cluster identifiers must be accompanied by knowledge of the profile identifier to be processed. Prior to any messages being directed to a device, it is assumed by the ZigBee protocol that service discovery has been employed to determine profile support on devices and endpoints. Likewise, the binding process assumes similar service discovery and profile matching has occurred, since the resulting match is distilled to source address, source endpoint, cluster identifier, destination address, and destination endpoint.

2.3.1.3 Deploying the Profile on Endpoints

A single ZigBee device may contain support for many profiles, provide for subsets of various cluster identifiers defined within those profiles, and may support multiple device descriptions. This capability is defined using a hierarchy of addressing within the device as follows:

- **Device:** the entire device is supported by a single radio with a unique IEEE and NWK address.
- **Endpoints:** this is an 8-bit field that describes different applications that are supported by a single radio. Endpoint 0x00 is used to address the device profile, which each ZigBee device must employ, endpoint 0xff is used to address all active endpoints (the broadcast endpoint). Consequently, a single

physical ZigBee radio can support up to 254 applications on endpoints 0x01-0xfe. Note that endpoints 0xf1-0xfe can only be used for ZigBee Alliance approved applications.

It is an application decision as to how to deploy applications on a device endpoint and which endpoints to advertise. The only requirement is that simple descriptors be created for each endpoint and those descriptors made available for service discovery.

2.3.1.4 Enabling Service Discovery

Once a device is created to support specific profiles and made consistent with cluster identifier usage for device descriptions within those profiles, the applications can be deployed. To do this, each application is assigned to individual endpoints and each described using simple descriptors (an endpoint can support only a single application profile). It is via the simple descriptors and other service discovery mechanisms described in the ZigBee device profile that service discovery is enabled, binding of devices is supported, and application messaging between complementary devices is facilitated.

One important point is that service discovery is made on the basis of profile identifier, input cluster identifier list, and output cluster identifier list (device description is notably missing). The device description is simply a convention for specifying mandatory and optional cluster identifier support within devices of that type for the indicated profile. Additionally, it is expected that the device description enumeration would be employed within PDAs or other assisted binding devices to provide external descriptions of device capabilities.

2.3.1.5 Mixing Standard and Proprietary Profiles

As an example, a ZigBee device could be developed to ZigBee public profile identifier “XX.” If a manufacturer wanted to deploy a ZigBee device supporting public profile “XX” and also provide manufacturer specific extensions, these extensions could be added to the manufacturer’s implementation of public profile “XX” if manufacturer extensions are supported within the definition of profile “XX.” Alternatively, if manufacturer extensions are not supported or the type of desired manufacturer extensions aren’t supported in profile “XX,” the manufacturer may deploy the extensions in a separate manufacturer-specific profile identifier advertised on a separate endpoint within the same physical device. In either case, devices that support the profile identifier “XX” but not containing the manufacturer extensions, would only advertise support for the base features of public profile identifier “XX” and could not respond to or create messages using the manufacturer extensions.

2.3.1.6 Enabling Backward Compatibility

In the previous example, a device is created using ZigBee public profile identifier “XX.” If the ZigBee Alliance were to update this public profile at a later time to add new features, the revisions could either be incorporated directly into public profile identifier “XX” if such extensions are supported via the definition of the profile, or could be introduced into a new public profile with a new profile identifier (say “XY”). Assuming extensibility is not supported in public profile “XX,” devices manufactured with just profile identifier “XX” could still be compatible with newer devices manufactured later by having the newer devices advertise support for both profile identifier “XX” and profile identifier “XY.” In this manner, the newer device may communicate with older devices using profile identifier “XX,” however, it may also communicate with newer devices using profile identifier “XY” from within the same application. The service discovery feature within ZigBee enables devices on the network to determine the level of support.

It is the goal of the ZigBee Alliance to provide extensibility, both for manufacturer extensions to public profiles as well as future enhancements to public profiles. That goal includes maintaining those extensions and enhancements within the same profile identifier whenever possible. This section illustrates that the profile definition features within ZigBee permit deployment of manufacturer extensions and feature enhancements, whether the goal of profile extensibility is achievable or not. The subject of profile extensibility, both for manufacturer extensions and feature enhancements, is beyond the scope of this document and addressed in other Alliance documents.

2.3.2 ZigBee Descriptors

ZigBee devices describe themselves using descriptor data structures. The actual data contained in these descriptors is defined in the individual device descriptions. There are five descriptors: node, node power, simple, complex, and user, shown in Table 2.28.

Table 2.28 ZigBee Descriptors

Descriptor Name	Status	Description
Node	M	Type and capabilities of the node.
Node power	M	Node power characteristics.
Simple	M	Device descriptions contained in node.
Complex	O	Further information about the device descriptions.
User	O	User-definable descriptor.

2.3.2.1 Transmission of Descriptors

The node, node power, simple, and user descriptors shall be transmitted in the order that they appear in their respective tables, *i.e.*, the field at the top of the table is transmitted first and the field at the bottom of the table is transmitted last. Each individual field shall follow the transmission order specified in sub-clause 1.2.1.4.

Each descriptor shall be less than or equal to *apscMaxDescriptorSize* unless provision has been made to enable transmission of discovery information without the mandatory use of fragmentation.

In the case of the Simple Descriptor (see 2.3.2.5), transmission primitives exist which permit the descriptor to extend beyond *apscMaxDescriptorSize* (see 2.4.3.1.21 and 2.4.4.1.20). When extended transmission primitives are employed, the standard transmission primitives (see 2.4.3.1.5 and 2.4.4.1.5) require transmission of an abbreviated Simple Descriptor, and the Node Descriptor of the device shall indicate availability of extended transmission primitives (see 2.3.2.3.12).

The complex descriptor shall be formatted and transmitted as illustrated in Figure 2.15.

Octets: 1	Variable	...	Variable
Field count	Field 1	...	Field <i>n</i>

Figure 2.15 Format of the Complex Descriptor

Each field included in the complex descriptor shall be formatted as illustrated in Figure 2.16.

Octets: 1	Variable
Compressed XML tag	Field data

Figure 2.16 Format of an Individual Complex Descriptor Field

2.3.2.1.1 Field Count Field

The field count field is one octet in length and specifies the number of fields included in the Complex Descriptor, each formatted as illustrated in Figure 2.16.

2.3.2.1.1.1 Compressed XML Tag Field

The compressed XML tag field is one octet in length and specifies the XML tag for the current field. The compressed XML tags for the complex descriptor are listed in Table 2.41.

2.3.2.1.1.2 Field Data Field

The field data field has a variable length and contains the information specific to the current field, as indicated by the compressed XML tag field.

2.3.2.2 Discovery via Descriptors

Descriptor information is queried in the ZDO management entity device and service discovery, using the ZigBee device profile request primitive addressed to endpoint 0. For details of the discovery operation, see sub-clause 2.4.2.1. Information is returned via the ZigBee device profile indication primitive.

The node, node power, complex, and user descriptors apply to the complete node. The simple descriptor must be specified for each endpoint defined in the node. If a node contains multiple subunits, these will be on separate endpoints and the specific descriptors for these endpoints are read by including the relevant endpoint number in the ZigBee device profile primitive.

2.3.2.3 Node Descriptor

The node descriptor contains information about the capabilities of the ZigBee node and is mandatory for each node. There shall be only one node descriptor in a node.

The fields of the node descriptor are shown in Table 2.29 in their order of transmission.

Table 2.29 Fields of the Node Descriptor

Field Name	Length (Bits)
Logical type	3
Complex descriptor available	1
User descriptor available	1
Reserved	3
APS flags	3
Frequency band	5
MAC capability flags	8
Manufacturer code	16
Maximum buffer size	8
Maximum incoming transfer size	16
Server mask	16
Maximum outgoing transfer size	16
Descriptor capability field	8

2.3.2.3.1 Logical Type Field

The logical type field of the node descriptor is three bits in length and specifies the device type of the ZigBee node. The logical type field shall be set to one of the non-reserved values listed in Table 2.30.

Table 2.30 Values of the Logical Type Field

Logical Type Value $b_2b_1b_0$	Description
000	ZigBee coordinator
001	ZigBee router
010	ZigBee end device
011-111	Reserved

2.3.2.3.2 Complex Descriptor Available Field

The complex descriptor available field of the node descriptor is one bit in length and specifies whether a complex descriptor is available on this device. If this field is set to 1, a complex descriptor is available. If this field is set to 0, a complex descriptor is not available.

2.3.2.3.3 User Descriptor Available Field

The user descriptor available field of the node descriptor is one bit in length and specifies whether a user descriptor is available on this device. If this field is set to 1, a user descriptor is available. If this field is set to 0, a user descriptor is not available.

2.3.2.3.4 APS Flags Field

The APS flags field of the node descriptor is three bits in length and specifies the application support sub-layer capabilities of the node.

This field is currently not supported and shall be set to zero.

2.3.2.3.5 Frequency Band Field

The frequency band field of the node descriptor is five bits in length and specifies the frequency bands that are supported by the underlying IEEE 802.15.4 radio utilized by the node. For each frequency band supported by the underlying IEEE

802.15.4 radio, the corresponding bit of the frequency band field, as listed in Table 2.31, shall be set to 1. All other bits shall be set to 0.

Table 2.31 Values of the Frequency Band Field

Frequency Band Field Bit Number	Supported Frequency Band
0	868 – 868.6 MHz
1	Reserved
2	902 – 928 MHz
3	2400 – 2483.5 MHz
4	Reserved

2.3.2.3.6 MAC Capability Flags Field

The MAC capability flags field is eight bits in length and specifies the node capabilities, as required by the IEEE 802.15.4-2003 MAC sub-layer [B1]. The MAC capability flags field shall be formatted as illustrated in Figure 2.17.

Bits: 0	1	2	3	4-5	6	7
Alternate PAN coordinator	Device type	Power source	Receiver on when idle	Reserved	Security capability	Allocate address

Figure 2.17 Format of the MAC Capability Flags Field

The alternate PAN coordinator sub-field is one bit in length and shall be set to 1 if this node is capable of becoming a PAN coordinator. Otherwise, the alternative PAN coordinator sub-field shall be set to 0.

The device type sub-field is one bit in length and shall be set to 1 if this node is a full function device (FFD). Otherwise, the device type sub-field shall be set to 0, indicating a reduced function device (RFD).

The power source sub-field is one bit in length and shall be set to 1 if the current power source is mains power. Otherwise, the power source sub-field shall be set to 0. This information is derived from the node current power source field of the node power descriptor.

The receiver on when idle sub-field is one bit in length and shall be set to 1 if the device does not disable its receiver to conserve power during idle periods. Otherwise, the receiver on when idle sub-field shall be set to 0 (see also sub-clause 2.3.2.4.)

The security capability sub-field is one bit in length and shall be set to 1 if the device is capable of sending and receiving frames secured using the security suite specified in [B1]. Otherwise, the security capability sub-field shall be set to 0.

The allocate address sub-field is one bit in length and shall be set to 0 or 1.

2.3.2.3.7 Manufacturer Code Field

The manufacturer code field of the node descriptor is sixteen bits in length and specifies a manufacturer code that is allocated by the ZigBee Alliance, relating the manufacturer to the device.

2.3.2.3.8 Maximum Buffer Size Field

The maximum buffer size field of the node descriptor is eight bits in length, with a valid range of 0x00-0x7f. This field specifies the maximum size, in octets, of the network sub-layer data unit (NSDU) for this node. This is the maximum size of data or commands passed to or from the application by the application support sub-layer, before any fragmentation or re-assembly.

This field can be used as a high-level indication for network management.

2.3.2.3.9 Maximum Incoming Transfer Size Field

The maximum transfer size field of the node descriptor is sixteen bits in length, with a valid range of 0x0000-0x7fff. This field specifies the maximum size, in octets, of the application sub-layer data unit (ASDU) that can be transferred to this node in one single message transfer. This value can exceed the value of the node maximum buffer size field (see sub-clause 2.3.2.3.8) through the use of fragmentation.

2.3.2.3.10 Server Mask Field

The server mask field of the node descriptor is sixteen bits in length, with bit settings signifying the system server capabilities of this node. It is used to facilitate discovery of particular system servers by other nodes on the system. The bit settings are defined in Table 2.32.

Table 2.32 Server Mask Bit Assignments

Bit Number	Assignment
0	Primary Trust Center
1	Backup Trust Center
2	Primary Binding Table Cache
3	Backup Binding Table Cache
4	Primary Discovery Cache

Table 2.32 Server Mask Bit Assignments (Continued)

Bit Number	Assignment
5	Backup Discovery Cache
6	Network Manager
7 – 15	Reserved

2.3.2.3.11 Maximum Outgoing Transfer Size Field

The maximum transfer size field of the node descriptor is sixteen bits in length, with a valid range of 0x0000-0x7fff. This field specifies the maximum size, in octets, of the application sub-layer data unit (ASDU) that can be transferred from this node in one single message transfer. This value can exceed the value of the node maximum buffer size field (see sub-clause 2.3.2.3.8) through the use of fragmentation.

2.3.2.3.12 Descriptor Capability Field

The descriptor capability field of the node descriptor is eight bits in length, with bit settings signifying the descriptor capabilities of this node. It is used to facilitate discovery of particular features of the descriptor fields by other nodes on the system. The bit settings are defined in Table 2.33.

Table 2.33 Descriptor Capability Bit Assignments

Bit Number	Assignment
0	Extended Active Endpoint List Available
1	Extended Simple Descriptor List Available
2-7	Reserved

2.3.2.4 Node Power Descriptor

The node power descriptor gives a dynamic indication of the power status of the node and is mandatory for each node. There shall be only one node power descriptor in a node.

The fields of the node power descriptor are shown in Table 2.34 in the order of their transmission.

Table 2.34 Fields of the Node Power Descriptor

Field Name	Length (Bits)
Current power mode	4

Table 2.34 Fields of the Node Power Descriptor (Continued)

Available power sources	4
Current power source	4
Current power source level	4

2.3.2.4.1 Current Power Mode Field

The current power mode field of the node power descriptor is four bits in length and specifies the current sleep/power-saving mode of the node. The current power mode field shall be set to one of the non-reserved values listed in Table 2.35.

Table 2.35 Values of the Current Power Mode Field

Current Power Mode Value $b_3b_2b_1b_0$	Description
0000	Receiver synchronized with the receiver on when idle sub-field of the node descriptor.
0001	Receiver comes on periodically as defined by the node power descriptor.
0010	Receiver comes on when stimulated, e.g. by a user pressing a button.
0011-1111	Reserved.

2.3.2.4.2 Available Power Sources Field

The available power sources field of the node power descriptor is four bits in length and specifies the power sources available on this node. For each power source supported on this node, the corresponding bit of the available power sources field, as listed in Table 2.36, shall be set to 1. All other bits shall be set to 0.

Table 2.36 Values of the Available Power Sources Field

Available Power Sources Field Bit Number	Supported Power Source
0	Constant (mains) power
1	Rechargeable battery
2	Disposable battery
3	Reserved

2.3.2.4.3 Current Power Source Field

The current power source field of the node power descriptor is four bits in length and specifies the current power source being utilized by the node. For the current

power source selected, the corresponding bit of the current power source field, as listed in Table 2.37, shall be set to 1. All other bits shall be set to 0.

Table 2.37 Values of the Current Power Sources Field

Current Power Source Field Bit Number	Current Power Source
0	Constant (mains) power
1	Rechargeable battery
2	Disposable battery
3	Reserved

2.3.2.4.4 Current Power Source Level Field

The current power source level field of the node power descriptor is four bits in length and specifies the level of charge of the power source. The current power source level field shall be set to one of the non-reserved values listed in Table 2.38.

Table 2.38 Values of the Current Power Source Level Field

Current Power Source Level Field $b_3b_2b_1b_0$	Charge Level
0000	Critical
0100	33%
1000	66%
1100	100%
All other values	Reserved

2.3.2.5 Simple Descriptor

The simple descriptor contains information specific to each endpoint contained in this node. The simple descriptor is mandatory for each endpoint present in the node.

The fields of the simple descriptor are shown in Table 2.39 in their order of transmission. As this descriptor needs to be transmitted over air, the overall length of the simple descriptor shall be less than or equal to *apscMaxDescriptorSize*.

Table 2.39 Fields of the Simple Descriptor

Field Name	Length (Bits)
Endpoint	8
Application profile identifier	16
Application device identifier	16
Application device version	4
Reserved	4
Application input cluster count	8
Application input cluster list	16*i (where <i>i</i> is the value of the application input cluster count)
Application output cluster count	8
Application output cluster list	16*o (where <i>o</i> is the value of the application output cluster count)

2.3.2.5.1 Endpoint Field

The endpoint field of the simple descriptor is eight bits in length and specifies the endpoint within the node to which this description refers. Applications shall only use endpoints 1-254. Endpoints 241-254 shall be used only with the approval of the ZigBee Alliance.

2.3.2.5.2 Application Profile Identifier Field

The application profile identifier field of the simple descriptor is sixteen bits in length and specifies the profile that is supported on this endpoint. Profile identifiers shall be obtained from the ZigBee Alliance.

2.3.2.5.3 Application Device Identifier Field

The application device identifier field of the simple descriptor is sixteen bits in length and specifies the device description supported on this endpoint. Device description identifiers shall be obtained from the ZigBee Alliance.

2.3.2.5.4 Application Device Version Field

The application device version field of the simple descriptor is four bits in length and specifies the version of the device description supported on this endpoint. The

application device version field shall be set to one of the non-reserved values listed in Table 2.40.

Table 2.40 Values of the Application Device Version Field

Application Device Version Value $b_3b_2b_1b_0$	Description
0000-1111	Specific values to be set by the application profile described by the application profile identifier in this descriptor. Default shall be 0000 unless otherwise defined by the application profile.

2.3.2.5.5 Application Input Cluster Count Field

The application input cluster count field of the simple descriptor is eight bits in length and specifies the number of input clusters, supported on this endpoint, that will appear in the application input cluster list field. If the value of this field is zero, the application input cluster list field shall not be included.

2.3.2.5.6 Application Input Cluster List

The application input cluster list of the simple descriptor is $16 \cdot i$ bits in length, where i is the value of the application input cluster count field. This field specifies the list of input clusters supported on this endpoint, for use during the service discovery and binding procedures.

The application input cluster list field shall be included only if the value of the application input cluster count field is greater than zero.

2.3.2.5.7 Application Output Cluster Count Field

The application output cluster count field of the simple descriptor is eight bits in length and specifies the number of output clusters, supported on this endpoint, that will appear in the application output cluster list field. If the value of this field is zero, the application output cluster list field shall not be included.

2.3.2.5.8 Application Output Cluster List

The application output cluster list of the simple descriptor is $16 \cdot o$ bits in length, where o is the value of the application output cluster count field. This field specifies the list of output clusters supported on this endpoint, for use during the service discovery and binding procedures.

The application output cluster list field shall be included only if the value of the application output cluster count field is greater than zero.

2.3.2.6 Complex Descriptor

The complex descriptor contains extended information for each of the device descriptions contained in this node. The use of the complex descriptor is optional.

Due to the extended and complex nature of the data in this descriptor, it is presented in XML form using compressed XML tags. Each field of the descriptor, shown in Table 2.41, can therefore be transmitted in any order. As this descriptor needs to be transmitted over air, the overall length of the complex descriptor shall be less than or equal to *apscMaxDescriptorSize*.

Table 2.41 Fields of the Complex Descriptor

Field Name	XML Tag	Compressed XML Tag Value x_1x_0	Data Type
Reserved	-	00	-
Language and character set	<languageChar>	01	See sub-clause 2.3.2.6.1
Manufacturer name	<manufacturerName>	02	Character string
Model name	<modelName>	03	Character string
Serial number	<serialNumber>	04	Character string
Device URL	<deviceURL>	05	Character string
Icon	<icon>	06	Octet string
Icon URL	<outliner>	07	Character string
Reserved	-	08 – ff	-

2.3.2.6.1 Language and Character Set Field

The language and character set field is three octets in length and specifies the language and character set used by the character strings in the complex descriptor. The format of the language and character set field is illustrated in Figure 2.18.

Octets: 2	1
ISO 639-1 language code	Character set identifier

Figure 2.18 Format of the Language and Character Set Field

The ISO 639-1 language code sub-field is two octets in length and specifies the language used for character strings, as defined in [B5].

The character set identifier sub-field is one octet in length and specifies the encoding used by the characters in the character set. This sub-field shall be set to one of the non-reserved values listed in Table 2.42.

Table 2.42 Values of the Character Set Identifier Sub-Field

Character Set Identifier Value	Bits Per Character	Description
0x00	8	ISO 646, ASCII character set. Each character is fitted into the least significant 7 bits of an octet with the most significant bit set to zero (see also [B6]).
0x01 – 0xff	-	Reserved.

If the language and character sets have not been specified, the language shall default to English (language code = “EN”) and the character set to ISO 646.

2.3.2.6.2 Manufacturer Name Field

The manufacturer name field has a variable length and contains a character string representing the name of the manufacturer of the device.

2.3.2.6.3 Model Name Field

The model name field has a variable length and contains a character string representing the name of the manufacturers model of the device.

2.3.2.6.4 Serial Number Field

The serial number field has a variable length and contains a character string representing the manufacturers serial number of the device.

2.3.2.6.5 Device URL Field

The device URL field has a variable length and contains a character string representing the URL through which more information relating to the device can be obtained.

2.3.2.6.6 Icon Field

The icon field has a variable length and contains an octet string which carries the data for an icon that can represent the device on a computer, gateway, or PDA. The format of the icon shall be a 32-by-32-pixel PNG image.

2.3.2.6.7 Icon URL Field

The icon URL field has a variable length and contains a character string representing the URL through which the icon for the device can be obtained.

2.3.2.7 User Descriptor

The user descriptor contains information that allows the user to identify the device using a user-friendly character string, such as “Bedroom TV” or “Stairs light”. The use of the user descriptor is optional. This descriptor contains a single field, which uses the ASCII character set, and shall contain a maximum of 16 characters.

The fields of the user descriptor are shown in Table 2.43 in the order of their transmission.

Table 2.43 Fields of the User Descriptor

Field Name	Length (Octets)
User description	16

2.3.3 Functional Description

2.3.3.1 Reception and Rejection

The application framework shall be able to filter frames arriving via the APS sub-layer data service and only present the frames that are of interest to the applications implemented on each active endpoint.

The application framework receives data from the APS sub-layer via the APSDE-DATA.indication primitive and is targeted at a specific endpoint (DstEndpoint parameter) and a specific profile (ProfileId parameter).

If the application framework receives a frame for an inactive endpoint, the frame shall be discarded. Otherwise, the application framework shall determine whether the specified profile identifier matches the identifier of the profile implemented on the specified endpoint. If the profile identifier of the frame does not match and is not 0xFFFF (the wildcard Profile ID), the application framework shall reject the frame. If the wildcard profile ID is used, the application framework shall determine if the profile implemented on the specified endpoint is within the Standard profile range as dictated by document [B25]. If the wildcard profile ID is used for the received message and the profile ID on the destination endpoint is not within the Standard profile range (for example it is in the Private or Reserved ranges), the message shall be dropped.¹⁰

Otherwise, the application framework shall pass the payload of the received frame to the application implemented on the specified endpoint.

10. CCB 1224

2.4 The ZigBee Device Profile

2.4.1 Scope

This ZigBee Application Layer Specification describes how general ZigBee device features such as Binding, Device Discovery, and Service Discovery are implemented within ZigBee Device Objects. The ZigBee Device Profile operates like any ZigBee profile by defining clusters. Unlike application specific profiles, the clusters within the ZigBee Device Profile define capabilities supported in all ZigBee devices. As with any profile document, this document details the mandatory and/or optional clusters.

2.4.2 Device Profile Overview

The Device Profile supports four key inter-device communication functions within the ZigBee protocol. These functions are explained in the following sections:

- Device and Service Discovery Overview
- End Device Bind Overview
- Bind and Unbind Overview
- Binding Table Management Overview
- Network Management Overview

2.4.2.1 Device and Service Discovery Overview

Device and Service Discovery are distributed operations where individual devices or designated discovery cache devices respond to discovery requests. The “device address of interest” field enables responses from either the device itself or a discovery cache device. In selected cases where *both* the discovery cache device and the “device address of interest” device respond, the response from the “device address of interest” shall be used.

The following capabilities exist for device and service discovery:

- **Device Discovery:** Provides the ability for a device to determine the identity of other devices on the PAN. Device Discovery is supported for both the 64-bit IEEE address and the 16-bit Network address.
 - Device Discovery messages can be used in one of two ways:
 - Broadcast addressed:** All devices on the network shall respond according to the Logical Device Type and the matching criteria. ZigBee End Devices shall respond with just their address. ZigBee Coordinators and

ZigBee Routers with associated devices shall respond with their address as the first entry followed by the addresses of their associated devices depending on the type of request. The responding devices shall employ APS acknowledged service on the unicast responses.

—**Unicast addressed:** Only the specified device responds. A ZigBee End Device shall respond only with its address. A ZigBee Coordinator or Router shall reply with its own address and the address of each associated child device. Inclusion of the associated child devices allows the requestor to determine the network topology underlying the specified device.

- **Service Discovery:** Provides the ability for a device to determine services offered by other devices on the PAN.

- Service Discovery messages can be used in one of two ways:

—**Broadcast addressed:** Due to the volume of information that could be returned, only the individual device or the primary discovery cache shall respond with the matching criteria established in the request. The primary discovery cache shall only respond in this case if it holds cached discovery information for the NWKAddrOfInterest from the request. The responding devices shall also employ APS acknowledged service on the unicast responses.

—**Unicast addressed:** Only the specified device shall respond. In the case of a ZigBee Coordinator or ZigBee Router, these devices shall cache the Service Discovery information for sleeping associated devices and respond on their behalf.

- Service Discovery is supported with the following query types:

—**Active Endpoint:** This command permits an enquiring device to determine the active endpoints. An active endpoint is one with an application supporting a single profile, described by a Simple Descriptor. The command shall be unicast addressed.

—**Match Simple Descriptor:** This command permits enquiring devices to supply a Profile ID (and, optionally, lists of input and/or output Cluster IDs) and ask for a return of the identity of an endpoint on the destination device which matches the supplied criteria. This command may be broadcast to all devices for which macRxOnWhenIdle = TRUE, or unicast addressed. For broadcast addressed requests, the responding device shall employ APS acknowledged service on the unicast responses.

- Simple Descriptor:** This command permits an enquiring device to return the Simple Descriptor for the supplied endpoint. This command shall be unicast addressed.
- Node Descriptor:** This command permits an enquiring device to return the Node Descriptor from the specified device. This command shall be unicast addressed.
- Power Descriptor:** This command permits an enquiring device to return the Power Descriptor from the specified device. This command shall be unicast addressed.
- Complex Descriptor:** This optional command permits an enquiring device to return the Complex Descriptor from the specified device. This command shall be unicast addressed.
- User Descriptor:** This optional command permits an enquiring device to return the User Descriptor from the specified device. This command shall be unicast addressed.

2.4.2.2 End Device Bind Overview

The following capabilities exist for end device bind:

- **End Device Bind:**
 - Provides the ability for an application to support a simplified method of binding where user intervention is employed to identify command/control device pairs. Typical usage would be where a user is asked to push buttons on two devices for installation purposes. Using this mechanism a second time allows the user to remove the binding table entry.

2.4.2.3 Bind and Unbind Overview

The following capabilities exist for directly configuring binding table entries:

- **Bind:** provides the ability for creation of a Binding Table entry that maps control messages to their intended destination.
- **Unbind:** provides the ability to remove Binding Table entries.

2.4.2.4 Binding Table Management Overview

The following capabilities exist for management of binding tables:

- Registering devices that implement source binding:
 - Provides the ability for a source device to instruct its primary binding table cache to hold its own binding table.

- Replacing a device with another wherever it occurs in the binding table:
 - Provides the ability to replace one device for another, by replacing all instances of its address in the binding table.
- Backing up a binding table entry:
 - Provides the ability for a primary binding table cache to send details of a newly created entry to the backup binding table cache (after receiving a bind request).
- Removing a backup binding table entry:
 - Provides the ability for a primary binding table cache to request that a specific entry be removed from the backup binding table cache (after receiving an unbind request).
- Backing up of the entire binding table:
 - Provides the ability for a primary binding table cache to request backup of its entire binding table, using the backup binding table cache.
- Restoring the entire binding table:
 - Provides the ability for a primary binding table cache to request restoration of its entire binding table, using the backup binding table cache.
- Backing up the Primary Binding Table Cache:
 - Provides the ability for a primary binding table cache to request backup of its entire source devices address table (which contains the addresses of any source device containing its own binding table).
- Restoring the Primary Binding Table Cache:
 - Provides the ability for a primary binding table cache to request restoration of its entire source devices address table (which contains the addresses of any source device containing its own binding table).

2.4.2.5 Network Management Overview

The following capabilities exist for network management:

- Provides the ability to retrieve management information from the devices including:
 - Network discovery results
 - Link quality to neighbor nodes
 - Routing table contents
 - Binding table contents

- Discovery cache contents
- Energy detection scan results
- Provides the ability to set management information controls including:
 - Network leave
 - Network direct join
 - Permit joining
 - Network update and fault notification

2.4.2.6 Device Descriptions for the Device Profile

The ZigBee Device Profile utilizes a single Device Description. Each cluster specified as Mandatory shall be present in all ZigBee devices. The response behavior to some messages is logical device type specific. The support for optional clusters is not dependent on the logical device type.

2.4.2.7 Configuration and Roles

The Device Profile assumes a client/server topology. A device making Device Discovery, Service Discovery, Binding or Network Management requests does so via a client role. A device which services these requests and responds does so via a server role. The client and server roles are non-exclusive in that a given device may supply both client and server roles.

Since many client requests and server responses are public and accessible to application objects other than ZigBee Device Objects, the Transaction Sequence number in the Application Framework header shall be the same on client requests and their associated server responses.

The Device Profile describes devices in one of two configurations:

- **Client:** A client issues requests to the server via Device Profile messages.
- **Server:** A server issues responses to the client that initiated the Device Profile message.

2.4.2.8 Transmission of ZDP Commands

All ZDP commands shall be transmitted via the APS data service and shall be formatted according to the ZDP frame structure, as illustrated in Figure 2.19.

Octets: 1	Variable
Transaction sequence number	Transaction data

Figure 2.19 Format of the ZDP Frame

2.4.2.8.1 Transaction Sequence Number Field

The transaction sequence number field is eight bits in length and specifies an identification number for the ZDP transaction so that a response command frame can be related to the request frame. The application object itself shall maintain an eight-bit counter that is copied into this field and incremented by one for each command sent. When a value of 0xff is reached, the next command shall restart the counter with a value of 0x00.

If a device sends a ZDP request command that requires a response, the target device shall respond with the relevant ZDP response command and include the transaction sequence number contained in the original request command.

The transaction sequence number field can be used by a controlling device, which may have issued multiple commands, so that it can match the incoming responses to the relevant command.

2.4.2.8.2 Transaction Data Field

The transaction data field has a variable length and contains the data for the individual ZDP transaction. The format and length of this field is dependent on the command being transmitted, as defined in sub-clauses 2.4.3 and 2.4.4.

2.4.3 Client Services

The Device Profile Client Services support the transport of device and service discovery requests, end device binding requests, bind requests, unbind requests, and network management requests from client to server. Additionally, Client Services support receipt of responses to these requests from the server.

2.4.3.1 Device and Service Discovery Client Services

Table 2.44 lists the commands supported by Device Profile, Device, and Service Discovery Client Services. Each of these commands will be discussed in the following sub-clauses.

Table 2.44 Device and Service Discovery Client Services Commands

Device and Service Discovery Client Services	Client Transmission	Server Processing
NWK_addr_req	O	M
IEEE_addr_req	O	M
Node_Desc_req	O	M
Power_Desc_req	O	M
Simple_Desc_req	O	M

Table 2.44 Device and Service Discovery Client Services Commands (Continued)

Active_EP_req	O	M
Match_Desc_req	O	M
Complex_Desc_req	O	O
User_Desc_req	O	O
Discovery_Cache_req	O	O
Device_annce	O	M
User_Desc_set	O	O
System_Server_Discover_req	O	O
Discovery_store_req	O	O
Node_Desc_store_req	O	O
Power_Desc_store_req	O	O
Active_EP_store_req	O	O
Simple_Desc_store_req	O	O
Remove_node_cache_req	O	O
Find_node_cache_req	O	O
Extended_Simple_Desc_req	O	O
Extended_Active_EP_req	O	O

2.4.3.1.1 NWK_addr_req

The NWK_addr_req command (ClusterID=0x0000) shall be formatted as illustrated in Figure 2.20.

Octets: 8	1	1
IEEEAddress	RequestType	StartIndex

Figure 2.20 Format of the NWK_addr_req Command

Table 2.45 specifies the fields of the NWK_addr_req Command Frame.

Table 2.45 Fields of the NWK_addr_req Command

Name	Type	Valid Range	Description
IEEEAddr	IEEE Address	A valid 64-bit IEEE address	The IEEE address to be matched by the Remote Device
RequestType	Integer	0x00-0xff	Request type for this command: 0x00 – Single device response 0x01 – Extended response 0x02-0xFF – reserved
StartIndex	Integer	0x00-0xff	If the Request type for this command is Extended response, the StartIndex provides the starting index for the requested elements of the associated devices list

2.4.3.1.1.1 When Generated

The NWK_addr_req is generated from a Local Device wishing to inquire as to the 16-bit address of the Remote Device based on its known IEEE address. The destination addressing on this command shall be unicast or broadcast to all devices for which macRxOnWhenIdle = TRUE.

2.4.3.1.1.2 Effect on Receipt

Upon receipt, a Remote Device shall compare the IEEEAddr to its local IEEE address or any IEEE address held in its local discovery cache. If there is no match and the request was unicast, a NWK_addr_resp command shall be generated and sent back to the local device with the Status field set to DEVICE_NOT_FOUND, the IEEEAddrRemoteDev field set to the IEEE address of the request; the NWKAddrRemoteDev field set to the NWK address of this device; and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame. If there is no match and the command was received as a broadcast, the request shall be discarded and no response generated.

If a match is detected between the contained IEEEAddr and the Remote Device's IEEE address or one held in the discovery cache, the RequestType shall be used to create a response. If the RequestType is one of the reserved values, a NWK_addr_resp command shall be generated and sent back to the local device with the Status field set to INV_REQUESTTYPE; the IEEEAddrRemoteDev field set to the IEEE address of the request; the NWKAddrRemoteDev field set to the network address corresponding to the IEEE address of the request; and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame.

If the RequestType is single device response, a NWK_addr_resp command shall be generated and sent back to the local device with the Status field set to SUCCESS, the IEEEAddrRemoteDev field set to the IEEE address of the request; the NWKAddrRemoteDev field set to the NWK address of the discovered device; and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame.

If the RequestType was Extended response and the Remote Device is either the ZigBee coordinator or router with associated devices, a NWK_addr_resp command shall be generated and sent back to the local device with the Status field set to SUCCESS, the IEEEAddrRemoteDev field set to the IEEE address of the device itself, and the NWKAddrRemoteDev field set to the NWK address of the device itself. The Remote Device shall also supply a list of all 16-bit NWK addresses in the NWKAddrAssocDevList field, starting with the entry StartIndex and continuing with whole entries until the maximum APS packet length is reached, for its associated devices. It shall then set the NumAssocDev field to the number of entries in the NWKAddrAssocDevList field.

2.4.3.1.2 IEEE_addr_req

The IEEE_addr_req command (ClusterID=0x0001) shall be formatted as illustrated in Figure 2.21.

Octets: 2	1	1
NWKAddrOfInterest	RequestType	StartIndex

Figure 2.21 Format of the IEEE_addr_req_Command Frame

Table 2.46 specifies the fields of the IEEE_addr_req command frame.

Table 2.46 Fields of the IEEE_addr_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address that is used for IEEE address mapping.
RequestType	Integer	0x00-0xff	Request type for this command: 0x00 – Single device response 0x01 – Extended response 0x02-0xff – reserved
StartIndex	Integer	0x00-0xff	If the Request type for this command is Extended response, the StartIndex provides the starting index for the requested elements of the associated devices list.

2.4.3.1.2.1 When Generated

The IEEE_addr_req is generated from a Local Device wishing to inquire as to the 64-bit IEEE address of the Remote Device based on their known 16-bit address. The destination addressing on this command shall be unicast.

2.4.3.1.2.2 Effect on Receipt

Upon receipt, a Remote Device shall compare the NWKAddrOfInterest to its local NWK address or any NWK address held in its local discovery cache. If there is no match, an IEEE_addr_resp command shall be generated and sent back to the local device with the Status field set to DEVICE_NOT_FOUND; the IEEEAddrRemoteDev field set to the IEEE address of this device; the NWKAddrRemoteDev field set to the NWK address of the request; and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame.

If a match is detected between the contained NWKAddrOfInterest and the Remote Device's NWK address or one held in the discovery cache, the RequestType shall be used to create a response. If the RequestType is one of the reserved values, an IEEE_addr_resp command shall be generated and sent back to the local device with the Status field set to INV_REQUESTTYPE, the IEEEAddrRemoteDev field set to the IEEE address of this device, the NWKAddrRemoteDev field set to the network address of this device and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame.

If the RequestType is single device response, an IEEE_addr_resp command shall be generated and sent back to the local device with the Status field set to SUCCESS, the IEEEAddrRemoteDev field set to the IEEE address of the discovered device, the NWKAddrRemoteDev field set to the NWK address of the request and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included in the frame.

If the RequestType indicates an Extended Response and the Remote Device is the ZigBee coordinator or router with associated devices, an IEEE_addr_resp command shall be generated and sent back to the local device with the Status field set to SUCCESS, the IEEEAddrRemoteDev field set to the IEEE address of the device itself, and the NWKAddrRemoteDev field set to the NWK address of the device itself. The Remote Device shall also supply a list of all 16-bit network addresses in the NWKAddrAssocDevList field, starting with the entry StartIndex and continuing with whole entries until the maximum APS packet length is reached, for its associated devices. It shall then set the NumAssocDev field to the number of entries in the NWKAddrAssocDevList field.

2.4.3.1.3 Node_Desc_req

The Node_Desc_req_command (ClusterID=0x0002) shall be formatted as illustrated in Figure 2.22.

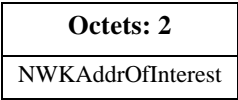


Figure 2.22 Format of the Node_Desc_req Command Frame

Table 2.47 specifies the fields for the Node_Desc_req command frame.

Table 2.47 Fields of the Node_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request

2.4.3.1.3.1 When Generated

The Node_Desc_req command is generated from a local device wishing to inquire as to the node descriptor of a remote device. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Node_Desc_req command using the format illustrated in Table 2.47. The NWKAddrOfInterest field shall contain the network address of the remote device for which the node descriptor is required.

2.4.3.1.3.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a Node_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.3.1.

2.4.3.1.4 Power_Desc_req

The Power_Desc_req command (ClusterID=0x0003) shall be formatted as illustrated in Figure 2.23.

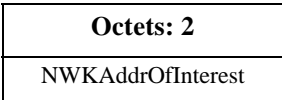


Figure 2.23 Format of the Power_Desc_req Command Frame

Table 2.48 specifies the fields of the Power_Desc_req command frame.

Table 2.48 Fields of the Power_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.

2.4.3.1.4.1 When Generated

The Power_Desc_req command is generated from a local device wishing to inquire as to the power descriptor of a remote device. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Power_Desc_req command using the format illustrated in Table 2.48. The NWKAddrOfInterest field shall contain the network address of the remote device for which the power descriptor is required.

2.4.3.1.4.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a Power_Desc_rsp command in response according to the description in sub-clause 2.4.4.1.4.1.

2.4.3.1.5 Simple_Desc_req

The Simple_Desc_req command (ClusterID=0x0004) shall be formatted as illustrated in Figure 2.24.

Octets: 2	1
NWKAddrOfInterest	EndPoint

Figure 2.24 Format of the Simple_Desc_req Command Frame

Table 2.49 specifies the fields of the Simple_Desc_req command frame.

Table 2.49 Fields of the Simple_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request
Endpoint	8 bits	1-254	The endpoint on the destination

2.4.3.1.5.1 When Generated

The Simple_Desc_req command is generated from a local device wishing to inquire as to the simple descriptor of a remote device on a specified endpoint. This

command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Simple_Desc_req command using the format illustrated in Table 2.49. The NWKAddrOfInterest field shall contain the network address of the remote device for which the simple descriptor is required and the endpoint field shall contain the endpoint identifier from which to obtain the required simple descriptor.

2.4.3.1.5.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a Simple_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.5.1.

2.4.3.1.6 Active_EP_req

The Active_EP_req command (ClusterID=0x0005) shall be formatted as illustrated in Figure 2.25.

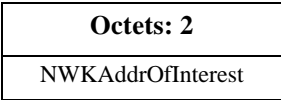


Figure 2.25 Format of the Active_EP_req Command Frame

Table 2.50 specifies the fields of the Active_EP_req command frame.

Table 2.50 Fields of the Active_EP_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.

2.4.3.1.6.1 When Generated

The Active_EP_req command is generated from a local device wishing to acquire the list of endpoints on a remote device with simple descriptors. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Active_EP_req command using the format illustrated in Table 2.50. The NWKAddrOfInterest field shall contain the network address of the remote device for which the active endpoint list is required.

2.4.3.1.6.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate an Active_EP_rsp command in response, according to the description in sub-clause 2.4.4.1.6.1.

2.4.3.1.7 Match_Desc_req

The Match_Desc_req command (ClusterID=0x0006) shall be formatted as illustrated in Figure 2.26.

Octets: 2	2	1	Variable	1	Variable
NWKAddrOfInterest	ProfileID	NumInClusters	InClusterList	NumOutClusters	OutClusterList

Figure 2.26 Format of the Match_Desc_req Command Frame

Table 2.51 specifies the fields of the Match_Desc_req command frame.

Table 2.51 Fields of the Match_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
ProfileID	Integer	0x0000-0xffff	Profile ID to be matched at the destination.
NumInClusters	Integer	0x00-0xff	The number of Input Clusters provided for matching within the InClusterList.
InClusterList	2 bytes * NumInClusters		List of Input ClusterIDs to be used for matching; the InClusterList is the desired list to be matched by the Remote Device (the elements of the InClusterList are the supported output clusters of the Local Device).
NumOutClusters	Integer	0x00-0xff	The number of Output Clusters provided for matching within OutClusterList.
OutClusterList	2 bytes * NumOutClusters		List of Output ClusterIDs to be used for matching; the OutClusterList is the desired list to be matched by the Remote Device (the elements of the OutClusterList are the supported input clusters of the Local Device).

2.4.3.1.7.1 When Generated

The Match_Desc_req command is generated from a local device wishing to find remote devices supporting a specific simple descriptor match criterion. This command shall either be broadcast to all devices for which macRxOnWhenIdle = TRUE, or unicast. If the command is unicast, it shall be directed either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Match_Desc_req command using the format illustrated in Table 2.51. The NWKAddrOfInterest field shall contain the network address indicating a broadcast to all devices for which macRxOnWhenIdle = TRUE (0xffff) if the command is to be broadcast, or the network address of the remote device for which the match is required.

The remaining fields shall contain the required criterion for which the simple descriptor match is requested. The ProfileID field shall contain the identifier of the profile for which the match is being sought or the wildcard profile ID of 0xFFFF.¹¹

The NumInClusters field shall contain the number of elements in the InClusterList field. If the value of this field is 0, the InClusterList field shall not be included. If the value of the NumInClusters field is not equal to 0, the InClusterList field shall contain the list of input cluster identifiers for which the match is being sought.

The NumOutClusters field shall contain the number of elements in the OutClusterList field. If the value of this field is 0, the OutClusterList field shall not be included. If the value of the NumOutClusters field is not equal to 0, the OutClusterList field shall contain the list of output cluster identifiers for which the match is being sought.

2.4.3.1.7.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a Match_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.7.1.

2.4.3.1.8 Complex_Desc_req

The Complex_Desc_req command (ClusterID=0x0010) shall be formatted as illustrated in Figure 2.27.

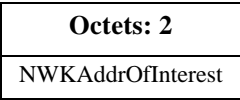


Figure 2.27 Format of the Complex_Desc_req Command Frame

11. CCB 1224

Table 2.52 specifies the fields of the Complex_Desc_req command frame.

Table 2.52 Fields of the Complex_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request

2.4.3.1.8.1 When Generated

The Complex_Desc_req command is generated from a local device wishing to inquire as to the complex descriptor of a remote device. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the Complex_Desc_req command using the format illustrated in Table 2.52. The NWKAddrOfInterest field shall contain the network address of the remote device for which the complex descriptor is required.

2.4.3.1.8.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a Complex_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.8.1.

2.4.3.1.9 User_Desc_req

The User_Desc_req (ClusterID=0x0011) command shall be formatted as illustrated in Figure 2.28.

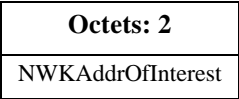


Figure 2.28 Format of the User_Desc_req Command Frame

Table 2.53 specifies the fields of the User_Desc_req command frame.

Table 2.53 Fields of the User_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.

2.4.3.1.9.1 When Generated

The User_Desc_req command is generated from a local device wishing to inquire as to the user descriptor of a remote device. This command shall be unicast either

to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the User_Desc_req command using the format illustrated in Table 2.53. The NWKAddrOfInterest field shall contain the network address of the remote device for which the user descriptor is required.

2.4.3.1.9.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a User_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.9.1.

2.4.3.1.10 Discovery_Cache_req

The Discovery_Cache_req command (ClusterID=0x0012) shall be formatted as illustrated in Figure 2.29.

Octets: 2	8
NWKAddr	IEEEAddr

Figure 2.29 Format of the Discovery_Cache_req Command Frame

Table 2.54 specifies the parameters for the Discovery_Cache_req command frame.

Table 2.54 Fields of the Discovery_Cache_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK address	NWK address for the Local Device.
IEEEAddr	Device Address	64-bit IEEE address	IEEE address for the Local Device.

2.4.3.1.10.1 When Generated

The Discovery_Cache_req is provided to enable devices on the network to locate a Primary Discovery Cache device on the network. The destination addressing on this primitive shall be broadcast to all devices for which macRxOnWhenIdle = TRUE.

2.4.3.1.10.2 Effect on Receipt

Upon receipt, if the Remote Device does not support the Discovery_Cache_req, the request shall be dropped and no further processing performed. If the Discovery_Cache_req is supported, the Remote Device shall create a unicast Discovery_Cache_rsp message to the source indicated by the Discovery_Cache_req and include a SUCCESS status.

2.4.3.1.11 Device_annce

The Device_annce command (ClusterID=0x0013) shall be formatted as illustrated in Figure 2.30.

Octets: 2	8	1
NWKAddr	IEEEAddr	Capability

Figure 2.30 Format of the Device_annce Command Frame

Table 2.55 specifies the fields of the Device_annce command frame.

Table 2.55 Fields of the Device_annce Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK address	NWK address for the Local Device
IEEEAddr	Device Address	64-bit IEEE address	IEEE address for the Local Device
Capability	Bitmap	See Figure 2.17	Capability of the local device

2.4.3.1.11.1 When Generated

The Device_annce is provided to enable ZigBee devices on the network to notify other ZigBee devices that the device has joined or re-joined the network, identifying the device's 64-bit IEEE address and new 16-bit NWK address, and informing the Remote Devices of the capability of the ZigBee device. This command shall be invoked for all ZigBee end devices upon join or rejoin. This command may also be invoked by ZigBee routers upon join or rejoin as part of NWK address conflict resolution. The destination addressing on this primitive is broadcast to all devices for which macRxOnWhenIdle = TRUE.

2.4.3.1.11.2 Effect on Receipt

Upon receipt, the Remote Device shall use the IEEEAddr in the message to find a match with any other IEEE address held in the Remote Device. If a match is detected, the Remote Device shall update the *nwkAddressMap* attribute of the NIB with the updated NWKAddr corresponding to the IEEEAddr received.

The Remote Device shall also use the NWKAddr in the message to find a match with any other 16-bit NWK address held in the Remote Device. If a match is detected for a device with an IEEE address other than that indicated in the IEEEAddr field received, then this entry shall be marked as not having a known valid 16-bit NWK address.

2.4.3.1.12 User_Desc_set

The User_Desc_set command (ClusterID=0x0014) shall be formatted as illustrated in Figure 2.31.

Octets: 2	1	Various
NWKAddrOfInterest	Length	UserDescriptor

Figure 2.31 Format of the User_Desc_set Command Frame

Table 2.56 specifies the fields of the User_Desc_set command frame.

Table 2.56 Fields of the User_Desc_set Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Length	Integer	0x00 - 0x10	Length of the User Descriptor in bytes.
UserDescription	User Descriptor		The user description to configure; if the ASCII character string to be entered here is less than 16 characters in length, it shall be padded with space characters (0x20) to make a total length of 16 characters. Characters with codes 0x00-0x1f are not permitted.

2.4.3.1.12.1 When Generated

The User_Desc_set command is generated from a local device wishing to configure the user descriptor on a remote device. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device.

The local device shall generate the User_Desc_set command using the format illustrated in Table 2.56. The NWKAddrOfInterest field shall contain the network address of the remote device for which the user descriptor is to be configured and the UserDescription field shall contain the ASCII character string that is to be configured in the user descriptor. Characters with ASCII codes numbered 0x00 through 0x1f are not permitted to be included in this string.

2.4.3.1.12.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate a User_Desc_conf command in response, according to the description in sub-clause 2.4.4.1.11.1.

2.4.3.1.13 System_Server_Discovery_req

The System_Server_Discovery_req command (ClusterID=0x0015) shall be formatted as illustrated in Figure 2.32.

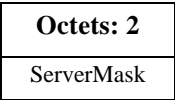


Figure 2.32 Format of the System_Server_Discovery_req Command Frame

Table 2.57 specifies the fields of the System_Server_Discovery_req command frame.

Table 2.57 Fields of the System_Server_Discovery_req Command

Name	Type	Valid Range	Description
ServerMask	Bitmap	16 bits	See Table 2.32 for bit assignments

2.4.3.1.13.1 When Generated

The System_Server_Discovery_req is generated from a Local Device wishing to discover the location of a particular system server or servers as indicated by the ServerMask parameter. The destination addressing on this request is ‘broadcast to all devices for which macRxOnWhenIdle = TRUE.’

2.4.3.1.13.2 Effect on Receipt

Upon receipt, remote devices shall compare the ServerMask parameter to the Server Mask field in their own Node descriptor. If no bits are found to match, no action is taken. If any matching bits are found, the remote device shall send a System_Server_Discovery_rsp back to the originator using unicast transmission (with acknowledgement request) and indicating the matching bits.

2.4.3.1.14 Discovery_store_req

The Discovery_Store_req command (ClusterID=0x0016) shall be formatted as illustrated in Figure 2.33.

Octets: 2	8	1	1	1	1	Variable
NWKAddr	IEEEAddr	NodeDesc-Size	PowerDesc-Size	ActiveEPSize	SimpleDesc-Count	SimpleDesc-SizeList

Figure 2.33 Format of the Discovery_Store_req Command Frame

Table 2.58 specifies the fields of the Discovery_store_req command frame.

Table 2.58 Fields of the Discovery_store_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the Local Device.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE Address for the Local Device.
NodeDescSize	Integer	0x00-0xff	Size in bytes of the Node Descriptor for the Local Device.
PowerDescSize	Integer	0x00 - 0xff	Size in bytes of the Power Descriptor for the Local Device.
ActiveEPSize	Integer	0x00 - 0xff	Size in bytes of the ActiveEPCount and ActiveEPList fields of the Active_EP_rsp for the Local Device.
SimpleDescCount	Integer	0x00 - 0xff	Number of Simple Descriptors supported by the Local Device (should be the same value as the ActiveEPSize).
SimpleDescSizeList	Array of bytes		List of bytes of SimpleDescCount length, each of which represents the size in bytes of the Simple Descriptor for each Active Endpoint on the Local Device.

2.4.3.1.14.1 When Generated

The Discovery_store_req is provided to enable ZigBee end devices on the network to request storage of their discovery cache information on a Primary Discovery Cache device. Included in the request is the amount of storage space the Local Device requires.

The destination addressing on this request is unicast.

2.4.3.1.14.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has storage for the requested discovery cache size determined by summing the sizes of the NWKAddr and IEEEAddr plus the NodeDescSize, PowerDescSize, ActiveEPSize, and the sizes from the SimpleDescSizeList. If sufficient space exists, the Local Device shall be provided a SUCCESS status. Otherwise, the Local Device shall return INSUFFICIENT_SPACE. If a SUCCESS status is returned, the Remote Device shall reserve the storage requested for the upload of the discovery information from the Local Device. Additionally, if the Local Device supplies an IEEEAddr which matches a previously stored entry, but the NWKAddr differs from the previous entry, the Remote Device shall remove the previous entry and discovery cache information in favor of the newly registered data.

2.4.3.1.15 Node_Desc_store_req

The Node_Desc_store_req command (ClusterID=0x0017) shall be formatted as illustrated in Figure 2.34.

Octets: 2	8	Variable
NWKAddr	IEEEAddr	NodeDescriptor

Figure 2.34 Format of the Node_Desc_store_req Command Frame

Table 2.59 specifies the fields of the Node_Desc_store_req command frame.

Table 2.59 Fields of the Node_Desc_store_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the Local Device
IEEEAddr	Device Address	64-bit IEEE Address	IEEE address for the Local Device
NodeDescriptor	Node Descriptor		See the Node Descriptor format in sub-clause 2.3.2.3

2.4.3.1.15.1 When Generated

The Node_Desc_store_req is provided to enable ZigBee end devices on the network to request storage of their Node Descriptor on a Primary Discovery Cache device which has previously received a SUCCESS status from a Discovery_store_req to the same Primary Discovery Cache device. Included in this request is the Node Descriptor the Local Device wishes to cache.

2.4.3.1.15.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has previously processed a Discovery_store_req for the Local Device and returned a status of SUCCESS. If a previous Discovery_store_req has not been processed with a SUCCESS status, the Remote Device shall return NOT_PERMITTED. Next, the Remote Device shall determine if enough space is available to store the Node Descriptor for the Local Device. If not, the Remote Device shall return INSUFFICIENT_SPACE. Finally, the Remote Device shall store the Node Descriptor for the Local Device and return SUCCESS. If the request returned a status of SUCCESS and the NWKAddr and IEEEAddr in the request referred to addresses already held in the Primary Discovery Cache, the descriptor in this request shall overwrite the previously held entry.

2.4.3.1.16 Power_Desc_store_req

The Power_Desc_store_req command (ClusterID=0x0018) shall be formatted as illustrated in Figure 2.35.

Octets: 2	8	Variable
NWKAddr	IEEEAddr	PowerDescriptor

Figure 2.35 Format of the Power_Desc_store_req Command Frame

Table 2.60 specifies the fields of the Power_Desc_store_req command frame.

Table 2.60 Fields of the Power_Desc_store_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the Local Device.
IEEEAddr	Device Address	64-bit Address	IEEE address for the Local Device.
PowerDescriptor	Power Descriptor		See the Power Descriptor format in sub-clause 2.3.2.4; This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.3.1.16.1 When Generated

The Power_Desc_store_req is provided to enable ZigBee end devices on the network to request storage of their Power Descriptor on a Primary Discovery Cache device which has previously received a SUCCESS status from a

Discovery_store_req to the same Primary Discovery Cache device. Included in this request is the Power Descriptor the Local Device wishes to cache.

2.4.3.1.16.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has previously processed a Discovery_store_req for the Local Device and returned a status of SUCCESS. If a previous Discovery_store_req has not been processed with a SUCCESS status, the Remote Device shall return NOT_PERMITTED. Next, the Remote Device shall determine if enough space is available to store the Power Descriptor for the Local Device. If not, the Remote Device shall return INSUFFICIENT_SPACE. Finally, the Remote Device shall store the Power Descriptor for the Local Device and return SUCCESS. If the request returned a status of SUCCESS, and the NWKAddr and IEEEAddr in the request referred to addresses already held in the Primary Discovery Cache, the descriptor in this request shall overwrite the previously held entry.

2.4.3.1.17 Active_EP_store_req

The Active_EP_store_req command (ClusterID=0x0019) shall be formatted as illustrated in Figure 2.36.

Octets: 2	8	1	Variable
NWKAddr	IEEEAddr	ActiveEPCount	ActiveEPList

Figure 2.36 Format of the Active_EP_store_req Command Frame

Table 2.61 specifies the fields of the Active_EP_store_req command frame

Table 2.61 Fields of the Active_EP_store_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the Local Device.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE Address for the Local Device.
ActiveEPCount	Integer	0x00-0xff	The count of active endpoints on the Local Device.
ActiveEPList			List of bytes, each of which represents an 8-bit endpoint number.

2.4.3.1.17.1 When Generated

The Active_EP_store_req is provided to enable ZigBee end devices on the network to request storage of their list of Active Endpoints on a Primary Discovery Cache device which has previously received a SUCCESS status from a Discovery_store_req to the same Primary Discovery Cache device. Included in this request is the count of Active Endpoints the Local Device wishes to cache and the endpoint list itself.

2.4.3.1.17.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has previously processed a Discovery_store_req for the Local Device and returned a status of SUCCESS. If a previous Discovery_store_req has not been processed with a SUCCESS status, the Remote Device shall return NOT_PERMITTED. Next, the Remote Device shall determine if enough space is available to store the Active Endpoint count and list for the Local Device. If not, the Remote Device shall return INSUFFICIENT_SPACE. Finally, the Remote Device shall store the Active Endpoint count and list for the Local Device and return SUCCESS. If the request returned a status of SUCCESS, and the NWKAddr and the IEEEAddr in the request referred to addresses already held in the Primary Discovery Cache, the descriptor in this request shall overwrite the previously held entry.

2.4.3.1.18 Simple_Desc_store_req

The Simple_Desc_store_req command (ClusterID=0x001a) shall be formatted as illustrated in Figure 2.37.

Octets: 2	8	1	Variable
NWKAddr	IEEEAddr	Length	SimpleDescriptor

Figure 2.37 Format of the Simple_Desc_store_req Command Frame

Table 2.62 specifies the fields of the Simple_Desc_store_req command frame.

Table 2.62 Fields of the Simple_Desc_store_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the Local Device.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE Address for the Local Device.
Length	Device Address	0x00 - 0xff	The length in bytes of the Simple Descriptor to follow.
SimpleDescriptor	Simple Descriptor		See the Simple Descriptor format in sub-clause 2.3.2.5.

2.4.3.1.18.1 When Generated

The Simple_desc_store_req is provided to enable ZigBee end devices on the network to request storage of their list of Simple Descriptors on a Primary Discovery Cache device which has previously received a SUCCESS status from a Discovery_store_req to the same Primary Discovery Cache device. Note that each Simple Descriptor for every active endpoint on the Local Device must be individually uploaded to the Primary Discovery Cache device via this command to enable cached discovery. Included in this request is the length of the Simple Descriptor the Local Device wishes to cache and the Simple Descriptor itself. The endpoint is a field within the Simple Descriptor and is accessed by the Remote Device to manage the discovery cache information for the Local Device.

2.4.3.1.18.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has previously processed a Discovery_store_req for the Local Device and returned a status of SUCCESS. If a previous Discovery_store_req has not been processed with a SUCCESS status, the Remote Device shall return NOT_PERMITTED. Next, the Remote Device shall determine if enough space is available to store the Simple Descriptor for the Local Device. If not, the Remote Device shall return INSUFFICIENT_SPACE. Finally, the Remote Device shall store the Simple Descriptor for the Local Device and return SUCCESS. If the request returned a status of SUCCESS and the NWKAddr and the IEEEAddr in the request referred to addresses already held in the Primary Discovery Cache, the descriptor in this request shall overwrite the previously held entry.

2.4.3.1.19 Remove_node_cache_req

The Remove_node_cache_req command (ClusterID=0x001b) shall be formatted as illustrated in Figure 2.38.

Octets: 2	8
NWKAddr	IEEEAddr

Figure 2.38 Format of the Remove_node_cache_req Command Frame

Table 2.63 specifies the fields of the Remove_node_cache_req command frame.

Table 2.63 Fields of the Remove_node_cache_req Command

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the device of interest.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE Address for the device of interest.

2.4.3.1.19.1 When Generated

The Remove_node_cache_req is provided to enable ZigBee devices on the network to request removal of discovery cache information for a specified ZigBee end device from a Primary Discovery Cache device. The effect of a successful Remove_node_cache_req is to undo a previously successful Discovery_store_req and additionally remove any cache information stored on behalf of the specified ZigBee end device on the Primary Discovery Cache device.

2.4.3.1.19.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache device. If it is not a Primary Discovery Cache device, the Remote Device shall return a status of NOT_SUPPORTED. Next, the Remote Device shall determine whether it has previously processed a Discovery_store_req for the indicated device and returned a status of SUCCESS. If a previous Discovery_store_req has not been processed with a SUCCESS status, the Remote Device shall return DEVICE_NOT_FOUND. Finally, the Remote Device shall remove all cached discovery information for the device of interest and return SUCCESS to the Local Device.

2.4.3.1.20 Find_node_cache_req

The Find_node_cache_req command (ClusterID=0x001c) shall be formatted as illustrated in Figure 2.39.

Octets: 2	8
NWKAddr	IEEEAddr

Figure 2.39 Format of the Find_node_cache Command Frame

Table 2.64 specifies the fields of the Find_node_cache_req command frame.

Table 2.64 Fields of the Find_node_cache_req Command Frame

Name	Type	Valid Range	Description
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the device of interest.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE Address for the device of interest.

2.4.3.1.20.1 When Generated

The Find_node_cache_req is provided to enable ZigBee devices on the network to broadcast to all devices for which macRxOnWhenIdle = TRUE a request to find a device on the network that holds discovery information for the device of interest, as specified in the request parameters. The effect of a successful Find_node_cache_req is to have the Primary Discovery Cache device, holding discovery information for the device of interest, unicast a Find_node_cache_rsp back to the Local Device. Note that, like the NWK_addr_req, only the device meeting this criteria shall respond to the request generated by Find_node_cache_req.

2.4.3.1.20.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is the device of interest or a Primary Discovery Cache device, and if so, if it holds discovery cache information for the device of interest. If it is not the device of interest or a Primary Discovery Cache device, and does not hold discovery cache information for the device of interest, the Remote Device shall cease processing the request and not supply a response. If the Remote Device is the device of interest, or a Primary Discovery Cache device, and, if the device holds discovery information for the indicated device of interest, the Remote Device shall return the NWKAddr and IEEEAddr for the device of interest.

2.4.3.1.21 Extended_Simple_Desc_req

The Extended_Simple_Desc_req command (ClusterID=0x001d) shall be formatted as illustrated in Figure 2.40.

Octets: 2	1	1
NWKAddrOfInterest	EndPoint	StartIndex

Figure 2.40 Format of the Extended_Simple_Desc_req Command Frame

Table 2.65 specifies the fields of the Extended_Simple_Desc_req command frame.

Table 2.65 Fields of the Extended_Simple_Desc_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Endpoint	8 bits	1-254	The endpoint on the destination.
StartIndex	8 bits	0x00-0xff	Starting index within the cluster list of the response represented by an ordered list of the Application Input Cluster List and Application Output Cluster List.

2.4.3.1.21.1 When Generated

The Extended_Simple_Desc_req command is generated from a local device wishing to inquire as to the simple descriptor of a remote device on a specified endpoint. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device. The Extended_Simple_Desc_req is intended for use with devices which employ a larger number of application input or output clusters than can be described by the Simple_Desc_req.

The local device shall generate the Extended_Simple_Desc_req command using the format illustrated in Table 2.65. The NWKAddrOfInterest field shall contain the network address of the remote device for which the simple descriptor is required and the endpoint field shall contain the endpoint identifier from which to obtain the required simple descriptor. The StartIndex is the first entry requested in the Application Input Cluster List and Application Output Cluster List sequence within the resulting response.

2.4.3.1.21.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate an Extended_Simple_Desc_rsp command in response, according to the description in sub-clause 2.4.4.1.20.1.

The results in the Extended_Simple_Desc_rsp shall include the elements described in Table 2.109 with a selectable set of the application input cluster and application output cluster lists starting with the entry StartIndex and continuing with whole entries until the maximum APS packet length is reached, along with a status of SUCCESS.

2.4.3.1.22 Extended_Active_EP_req

The Extended_Active_EP_req command (ClusterID=0x001e) shall be formatted as illustrated in Figure 2.41.

Octets: 2	1
NWKAddrOfInterest	StartIndex

Figure 2.41 Format of the Extended_Active_EP_req Command Frame

Table 2.66 specifies the fields of the Extended_Active_EP_req command frame.

Table 2.66 Fields of the Extended_Active_EP_req Command

Name	Type	Valid Range	Description
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
StartIndex	8 bits	0x00-0xff	Starting index within the Active Endpoint list in the response.

2.4.3.1.22.1 When Generated

The Extended_Active_EP_req command is generated from a local device wishing to acquire the list of endpoints on a remote device with simple descriptors. This command shall be unicast either to the remote device itself or to an alternative device that contains the discovery information of the remote device. The Extended_Active_EP_req is used for devices which support more active endpoints than can be returned by a single Active_EP_req.

The local device shall generate the Extended_Active_EP_req command using the format illustrated in Table 2.66. The NWKAddrOfInterest field shall contain the network address of the remote device for which the active endpoint list is required. The StartIndex field shall be set in the request to enable retrieval of lists of active endpoints from devices whose list exceeds the size of a single ASDU and where fragmentation is not supported.

2.4.3.1.22.2 Effect on Receipt

Upon receipt of this command, the recipient device shall process the command and generate an Extended_Active_EP_rsp command in response, according to the description in sub-clause 2.4.4.1.21.1.

The results in the Extended_Active_EP_rsp shall include the elements described in Table 2.110 with a selectable set of the list of active endpoints on the remote device starting with the entry StartIndex and continuing with whole entries until the maximum APS packet length is reached or the application input and output cluster lists is exhausted, along with a status of SUCCESS.

2.4.3.2 End Device Bind, Bind, Unbind, and Bind Management Client Services Primitives

Table 2.67 lists the primitives supported by Device Profile: End Device Bind, Bind and Unbind Client Services. Each of these commands will be discussed in the following sub-clauses.

Table 2.67 End Device Bind, Bind, Unbind, and Bind Management Client Service Commands

End Device Bind, Bind and Unbind Client Services	Client Transmission	Server Processing
End_Device_Bind_req	O	O
Bind_req	O	O
Unbind_req	O	O
Bind_Register_req	O	O
Replace_Device_req	O	O
Store_Bkup_Bind_Entry_req	O	O
Remove_Bkup_Bind_Entry_req	O	O
Backup_Bind_Table_req	O	O
Recover_Bind_Table_req	O	O
Backup_Source_Bind_req	O	O
Recover_Source_Bind_req	O	O

2.4.3.2.1 End_Device_Bind_req

The End_Device_Bind_req command (ClusterID=0x0020) shall be formatted as illustrated in Figure 2.42.

Octets: 2	8	1	2	1	Variable	1	Variable
Binding Target	SrcIEEE Address	Src Endpoint	Profile ID	Num InClusters	InCluster List	Num OutClusters	OutCluster List

Figure 2.42 Format of the End_Device_Bind_req Command Frame

Table 2.68 specifies the fields of the End_Device_Bind_req command frame.

Table 2.68 Fields of the End_Device_Bind_req Command

Name	Type	Valid Range	Description
BindingTarget	Device Address	16-bit NWK address	The address of the target for the binding. This can be either the primary binding cache device or the short address of the local device.
SrcIEEEAddress	IEEE Address	A valid 64-bit IEEE Address	The IEEE address of the device generating the request.
SrcEndpoint	8 bits	1-254	The endpoint on the device generating the request.
ProfileID	Integer	0x0000-0xffff	ProfileID which is to be matched between two End_Device_Bind_req received at the ZigBee Coordinator within the timeout value pre-configured in the ZigBee Coordinator.
NumInClusters	Integer	0x00-0xff	The number of Input Clusters provided for end device binding within the InClusterList.

Table 2.68 Fields of the End_Device_Bind_req Command (Continued)

Name	Type	Valid Range	Description
InClusterList	2 bytes * NumInClusters		List of Input ClusterIDs to be used for matching. The InClusterList is the desired list to be matched by the ZigBee coordinator with the Remote Device's output clusters (the elements of the InClusterList are supported input clusters of the Local Device).
NumOutClusters	Integer	0x00-0xff	The number of Output Clusters provided for matching within OutClusterList.
OutClusterList	2 bytes * NumOutClusters		List of Output ClusterIDs to be used for matching. The OutClusterList is the desired list to be matched by the ZigBee coordinator with the Remote Device's input clusters (the elements of the OutClusterList are supported output clusters of the Local Device).

2.4.3.2.1.1 When Generated

The End_Device_Bind_req is generated from a Local Device wishing to perform End Device Bind with a Remote Device. The End_Device_Bind_req is generated, typically based on some user action like a button press. The destination addressing on this command shall be unicast, and the destination address shall be that of the ZigBee Coordinator.

2.4.3.2.1.2 Effect on Receipt

On receipt of this command, the ZigBee coordinator shall first check that the supplied endpoint is within the specified range. If the supplied endpoint does not fall within the specified range, the ZigBee coordinator shall return an End_Device_Bind_rsp with a status of INVALID_EP.

If the supplied endpoint is within the specified range, the ZigBee Coordinator shall retain the End_Device_Bind_req for a pre-configured timeout duration awaiting a second End_Device_Bind_req. If the second request does not appear within the timeout period, the ZigBee Coordinator shall generate a TIMEOUT status and return it with the End_Device_Bind_rsp to the originating Local Device. Assuming the second End_Device_Bind_req is received within the timeout period, it shall be matched with the first request on the basis of the ProfileID, InClusterList and OutClusterList.

If no match of the ProfileID is detected or if the ProfileID matches but none of the InClusterList or OutClusterList elements match, a status of NO_MATCH shall be supplied to both Local Devices via End_Device_Bind_rsp to each device. If a

match of Profile ID and at least one input or output clusterID is detected, an End_Device_Bind_rsp with status SUCCESS shall be issued to each Local Device which generated the End_Device_Bind_req.

In order to facilitate a toggle action, the ZigBee Coordinator shall then issue an Unbind_req command to the BindingTarget, specifying any one of the matched ClusterID values. If the returned status value is NO_ENTRY, the ZigBee Coordinator shall issue a Bind_req command for each matched ClusterID value. Otherwise, the ZigBee Coordinator shall conclude that the binding records are instead to be removed and shall issue an Unbind_req command for any further matched ClusterID values.

The initial Unbind_req and any subsequent Bind_reqs or Unbind_reqs containing the matched clusters shall be directed to one of the BindingTargets specified by the generating devices. The BindingTarget is selected on an individual basis for each matched cluster, as the Binding Target selected by the generating device having that cluster as an output cluster. The SrcAddress field shall contain the 64-bit IEEE address of that same generating device and the SrcEndp field shall contain its endpoint. The DstAddress field shall contain the 64-bit IEEE address of the generating device having the matched cluster in its input cluster list and the DstEndp field shall contain its endpoint.

2.4.3.2.2 Bind_req

The Bind_req command (ClusterID=0x0021) shall be formatted as illustrated in Figure 2.43.

Octets: 8	1	2	1	2/8	0/1
SrcAddress	SrcEndp	ClusterID	DstAddrMode	DstAddress	DstEndp

Figure 2.43 Format of the Bind_req Command Frame

Table 2.69 specifies the fields of the Bind_req command frame.

Table 2.69 Fields of the Bind_req Command

Name	Type	Valid Range	Description
SrcAddress	IEEE Address	A valid 64-bit IEEE address	The IEEE address for the source.
SrcEndp	Integer	0x01-0xfe	The source endpoint for the binding entry.
ClusterID	Integer	0x0000-0xffff	The identifier of the cluster on the source device that is bound to the destination.

Table 2.69 Fields of the Bind_req Command (Continued)

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x00-0xff	The addressing mode for the destination address used in this command. This field can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddress and DstEndp not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddress and DstEndp present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode field	The destination address for the binding entry.
DstEndp	Integer	0x01-0xfe	This field shall be present only if the DstAddrMode field has a value of 0x03 and, if present, shall be the destination endpoint for the binding entry.

2.4.3.2.2.1 When Generated

The Bind_req is generated from a Local Device wishing to create a Binding Table entry for the source and destination addresses contained as parameters. The destination addressing on this command shall be unicast only, and the destination address shall be that of a Primary binding table cache or to the SrcAddress itself. The Binding Manager is optionally supported on the source device (unless that device is also the ZigBee Coordinator) so that device shall issue a NOT_SUPPORTED status to the Bind_req if not supported.

2.4.3.2.2.2 Effect on Receipt

Upon receipt, a Remote Device (a Primary binding table cache or the device designated by SrcAddress) shall create a Binding Table entry based on the parameters supplied in the Bind_req if the Binding Manager is supported. If the remote device is a primary binding table cache, the following additional processing is required. First, the primary cache shall check its table of devices holding their own source bindings for the device in SrcAddress and, if it is found, shall issue another Bind_req to that device with the same entry. Second, the primary cache shall check if there is a backup binding table cache and, if so, shall issue a Store_Bkup_Binding_Entry_req command to backup the new entry. The

Remote Device shall then respond with SUCCESS if the entry has been created by the Binding Manager; otherwise, the Remote Device shall respond with NOT_SUPPORTED.

This command shall be subject to a permissions check as defined in sub-clause 4.6.3.8. On failure, the remote device shall not carry out the command, and shall respond with NOT_AUTHORIZED.

2.4.3.2.3 Unbind_req

The Unbind_req command (ClusterID=0x0022) shall be formatted as illustrated in Figure 2.44.

Octets: 8	1	2	1	2/8	0/1
SrcAddress	SrcEndp	ClusterID	DstAddrMode	DstAddress	DstEndp

Figure 2.44 Format of the Unbind_req Command Frame

Table 2.70 specifies the fields of the Unbind_req command frame.

Table 2.70 Fields of the Unbind_req Command

Name	Type	Valid Range	Description
SrcAddress	IEEE Address	A valid 64-bit IEEE address	The IEEE address for the source
SrcEndp	Integer	0x01-0xfe	The source endpoint for the binding entry
ClusterID	Integer	0x0000-0xffff	The identifier of the cluster on the source device that is bound to the destination.
DstAddrMode	Integer	0x00-0xff	The addressing mode for the destination address used in this command. This field can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddress and DstEndp not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddress and DstEndp present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode field	The destination address for the binding entry.
DstEndp	Integer	0x01-00xfe	This field shall be present only if the DstAddrMode field has a value of 0x03 and, if present, shall be the destination endpoint for the binding entry.

2.4.3.2.3.1 When Generated

The Unbind_req is generated from a Local Device wishing to remove a Binding Table entry for the source and destination addresses contained as parameters. The destination addressing on this command shall be unicast only and the destination address must be that of the a Primary binding table cache or the SrcAddress.

2.4.3.2.3.2 Effect on Receipt

The Remote Device shall evaluate whether this request is supported. If the request is not supported, a Status of NOT_SUPPORTED shall be returned. If the request is supported, the Remote Device (a Primary binding table cache or the SrcAddress) shall remove a Binding Table entry based on the parameters supplied in the Unbind_req. If the Remote Device is a primary binding table cache, the following additional processing is required. First, the primary cache shall check its table of devices holding their own source bindings for the device in SrcAddress and, if it is found, shall issue another Unbind_req to that device with the same entry. Second, the primary cache shall check if there is a backup binding table cache and, if so, shall issue a Remove_Bkup_Bind_Entry_req command to remove the backup of this entry. If a Binding Table entry for the SrcAddress, SrcEndp, ClusterID, DstAddress, DstEndp contained as parameters does not exist, the Remote Device shall respond with NO_ENTRY. Otherwise, the Remote Device shall delete the indicated Binding Table entry and respond with SUCCESS.

This command shall be subject to a permissions check as defined in sub-clause 4.6.3.8. On failure the remote device shall not carry out the command, and shall respond with NOT_AUTHORIZED.

2.4.3.2.4 Bind_Register_req

The Bind_Register_req command (ClusterID=0x0023) shall be formatted as illustrated in Figure 2.45.

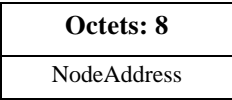


Figure 2.45 Format of the Bind_Register_req Command Frame

Table 2.71 specifies the fields for the Bind_Register_req command frame.

Table 2.71 Fields of the Bind_Register_req Command

Name	Type	Valid Range	Description
NodeAddress	IEEE Address	A valid 64-bit IEEE address	The address of the node wishing to hold its own binding table.

2.4.3.2.4.1 When Generated

The Bind_Register_req is generated from a Local Device and sent to a primary binding table cache device to register that the local device wishes to hold its own binding table entries. The destination addressing mode for this request is unicast.

2.4.3.2.4.2 Effect on Receipt

If the remote device is not a primary binding table cache it shall return a status of NOT_SUPPORTED. Otherwise, the primary binding table cache shall add the NodeAddress given by the parameter to its table of source devices which have chosen to store their own binding table. If this fails, it shall return a status of TABLE_FULL. Otherwise, it returns a status of SUCCESS. If an entry for the NodeAddress already exists in the table of source devices, the behavior will be the same as if it had been newly added. The source device should clear its source binding table before issuing this command to avoid synchronization problems. In the successful case, any existing bind entries from the binding table whose source address is NodeAddress will be sent to the requesting device for inclusion in its source binding table. See Bind_Register_rsp for further details. Subsequent bind entries written to the binding list will cause copies to be written to the source device using Bind_req.

2.4.3.2.5 Replace_Device_req

The Replace_Device_req command (ClusterID=0x0024) shall be formatted as illustrated in Figure 2.46.

Octets: 8	1	8	1
OldAddress	OldEndpoint	NewAddress	NewEndpoint

Figure 2.46 Format of the Replace_Device_req Command Frame

Table 2.72 specifies the fields for the Replace_Device_req command frame.

Table 2.72 Fields of the Replace_Device_req Command

Name	Type	Valid Range	Description
OldAddress	IEEE Address	A valid 64-bit IEEE	The address of the node being replaced.
OldEndpoint	Integer	0x00 - 0xfe	The endpoint being replaced.
NewAddress	IEEE Address	A valid 64-bit IEEE	The replacement address.
NewEndpoint	Integer	0x01 - 0xfe	The replacement endpoint.

2.4.3.2.5.1 When Generated

The Replace_Device_req is intended for use by a special device such as a Commissioning tool and is sent to a primary binding table cache device to change all binding table entries which match OldAddress and OldEndpoint as specified. Note that OldEndpoint = 0 has special meaning and signifies that only the address needs to be matched. The endpoint in the binding table will not be changed in this case and so NewEndpoint is ignored. The processing changes all binding table entries for which the source address is the same as OldAddress and, if OldEndpoint is non-zero, for which the source endpoint is the same as OldEndpoint. It shall also change all binding table entries which have the destination address the same as OldAddress and, if OldEndpoint is non-zero, the destination endpoint the same as OldEndpoint. The destination addressing mode for this request is unicast.

2.4.3.2.5.2 Effect on Receipt

If the remote device is not a primary binding table cache, it shall return a status of NOT_SUPPORTED. The primary binding table cache shall check if the OldAddress parameter is non-zero and, if so, shall search its binding table for entries of source addresses and source endpoint, or destination addresses and destination endpoint, that are set the same as OldAddress and OldEndpoint. It shall change these entries to have NewAddress and NewEndpoint. In the case that OldEndpoint is zero, the primary binding table cache shall search its binding table for entries whose source address or destination address match OldAddress. It shall change these entries to have NewAddress leaving the endpoint value unchanged and ignoring NewEndpoint. It shall then return a response of SUCCESS. The primary binding table cache shall also be responsible for notifying affected devices which are registered as holding their own source binding table of the changes. This will be necessary for each changed binding table entry, where the destination address was changed and the source address appears in the list of source devices which have chosen to store their own binding table. In each of these cases, the amended binding table entry will be sent to the source device using an Unbind_req command for the old entry followed by a Bind_req command for the new one. In the case that the source address of the bind entry has been changed, it will be necessary for the primary binding table cache to send an Unbind_req command to the old source device if it is a source bind device and to send a Bind_req command to the new source bind device if it is a source bind device. The primary binding table cache shall also update the backup binding table cache by means of the Remove_bkup_binding_entry_req command for the old entry and Store_bkup_binding_entry_req for the altered entry.

2.4.3.2.6 Store_Bkup_Bind_Entry_req

The Store_Bkup_Bind_Entry_req command (ClusterID=0x0025) shall be formatted as illustrated in Figure .

Octets: 8	1	2	1	2/8	0/1
SrcAddress	SrcEndp	ClusterID	DstAddrMode	DstAddress	DstEndp

Figure 2.47 Format of the Store_Bkup_Bind_Entry_req Command Frame

Table 2.73 specifies the fields of the Store_Bkup_Bind_Entry_req command frame.

Table 2.73 Fields of the Store_Bkup_Bind_Entry_req Command

Name	Type	Valid Range	Description
SrcAddress	IEEE Address	A valid 64-bit IEEE address	The IEEE address for the source.
SrcEndpoint	Integer	0x01 - 0xfe	The source endpoint for the binding entry.
ClusterId	Integer	0x0000 - 0xffff	The identifier of the cluster on the source device that is bound to the destination.
DstAddrMode	Integer	0x00-0xff	The addressing mode for the destination address used in this command. This field can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddress and DstEndp not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddress and DstEndp present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode field	The destination address for the binding entry.
DstEndp	Integer	0x01-0xfe	This field shall be present only if the DstAddrMode field has a value of 0x03 and, if present, shall be the destination endpoint for the binding entry.

2.4.3.2.6.1 When Generated

The Store_Bkup_Bind_Entry_req is generated from a local primary binding table cache and sent to a remote backup binding table cache device to request backup

storage of the entry. It will be generated whenever a new binding table entry has been created by the primary binding table cache. The destination addressing mode for this request is unicast.

2.4.3.2.6.2 Effect on Receipt

If the remote device is not a backup binding table cache it shall return a status of NOT_SUPPORTED. If it is the backup binding table cache, it should maintain the identity of the primary binding table cache from previous discovery. If the contents of the Store_Bkup_Bind_Entry parameters match an existing entry in the binding table cache, then the remote device shall return SUCCESS. Otherwise, the backup binding table cache shall add the binding entry to its binding table and return a status of SUCCESS. If there is no room, it shall return a status of TABLE_FULL.

2.4.3.2.7 Remove_Bkup_Bind_Entry_req

The Remove_Bkup_Bind_Entry_req command (ClusterID=0x0026) shall be formatted as illustrated in Figure 2.48.

Octets: 8	1	2	1	2/8	0/1
SrcAddress	SrcEndp	ClusterID	DstAddrMode	DstAddress	DstEndp

Figure 2.48 Format of the Remove_Bkup_Bind_Entry_req Command Frame

Table 2.74 specifies the fields of the Remove_Bkup_Bind_Entry_req command frame.

Table 2.74 Fields of the Remove_Bkup_Bind_Entry_req Command

Name	Type	Valid Range	Description
SrcAddress	IEEE Address	A valid 64-bit IEEE address	The IEEE address for the source.
SrcEndpoint	Integer	0x01 - 0xfe	The endpoint for the binding entry.
ClusterId	Integer	0x0000 - 0xffff	The identifier of the cluster on the source device that is bound to the destination.

Table 2.74 Fields of the Remove_Bkup_Bind_Entry_req Command (Continued)

DstAddrMode	Integer	0x00-0xff	The addressing mode for the destination address used in this command. This field can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddress and DstEndp not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddress and DstEndp present 0x04 – 0xff = reserved
DstAddress	Address	As specified by the DstAddrMode field	The destination address for the binding entry.
DstEndp	Integer	0x01-0xfe	This field shall be present only if the DstAddrMode field has a value of 0x03 and, if present, shall be the destination endpoint for the binding entry.

2.4.3.2.7.1 When Generated

The Remove_Bkup_Bind_Entry_req is generated from a local primary binding table cache and sent to a remote backup binding table cache device to request removal of the entry from backup storage. It will be generated whenever a binding table entry has been unbound by the primary binding table cache. The destination addressing mode for this request is unicast.

2.4.3.2.7.2 Effect on Receipt

If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If it is a backup binding table cache, it should maintain the identity of the primary binding table cache from previous discovery. If it does not recognize the sending device as the primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall search its binding table for the entry corresponding to the supplied parameters. If no entry is found, it shall return a status of NO_ENTRY. Otherwise, it shall delete the entry and return a status of SUCCESS.

2.4.3.2.8 Backup_Bind_Table_req

The Backup_Bind_Table_req command (ClusterID=0x0027) shall be formatted as illustrated in Figure 2.49.

Octets: 2	2	2	Variable
BindingTableEntries	StartIndex	BindingTableListCount	BindingTableList

Figure 2.49 Format of the Backup_Bind_Table_req Command Frame

Table 2.75 specifies the fields of the Backup_Bind_Table_req command frame.

Table 2.75 Fields of the Backup_Bind_Table_req Command

Name	Type	Valid Range	Description
BindingTableEntries	Integer	0x0000 - 0xffff	Total number of binding table entries on the primary binding table cache device.
StartIndex	Integer	0x0000 - 0xffff	Starting index within the binding table of entries.
BindingTableListCount	Integer	0x0000 - 0xffff	Number of binding table entries included within BindingTableList.
BindingTableList	List of binding descriptors	The list shall contain the number of elements given by the BindingTableListCount	A list of descriptors beginning with the StartIndex element and continuing for BindingTableListCount of the elements in the primary binding table cache devices's binding table (see Table 2.131 for details.)

2.4.3.2.8.1 When Generated

The Backup_Bind_Table_req is generated from a local primary binding table cache and sent to the remote backup binding table cache device to request backup storage of its entire binding table. The destination addressing mode for this request is unicast.

2.4.3.2.8.2 Effect on Receipt

If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If it is a backup binding table cache, it should maintain the identity of the primary binding table cache from previous discovery. If it does not recognize the sending device as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall

overwrite the binding entries in its binding table starting with StartIndex and continuing for BindingTableListCount entries. If this exceeds its table size, it shall fill in as many entries as possible and return a status of TABLE_FULL. Otherwise, it shall return a status of SUCCESS. The table is effectively truncated to the end of the last entry written by this request. The new size of the table is returned in the response and will be equal to StartIndex + BindingTableListCount unless TABLE_FULL is being returned in which case it will be the maximum size of the table.

2.4.3.2.9 Recover_Bind_Table_req

The Recover_Bind_Table_req command (ClusterID=0x0028) shall be formatted as illustrated in Figure 2.50.



Figure 2.50 Fields of the Recover_Bind_Table_req Command Frame

Table 2.76 specifies the fields of the Recover_Bind_Table_req command frame.

Table 2.76 Fields of the Recover_Bind_Table_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x0000 - 0xffff	Starting index for the requested elements of the binding table

2.4.3.2.9.1 When Generated

The Recover_Bind_Table_req is generated from a local primary binding table cache and sent to a remote backup binding table cache device when it wants a complete restore of the binding table. The destination addressing mode for this request is unicast.

2.4.3.2.9.2 Effect on Receipt

If the remote device is not the backup binding table cache, it shall return a status of NOT_SUPPORTED. If it does not recognize the sending device as a primary binding table cache it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall prepare a list of binding table entries from its backup beginning with StartIndex. It will fit in as many entries as possible into a Recover_Bind_Table_rsp command and return a status of SUCCESS.

2.4.3.2.10 Backup_Source_Bind_req

The Backup_Source_Bind_req command (ClusterID=0x0029) shall be formatted as illustrated in Figure 2.51.

Octets: 2	2	2	Variable
SourceTableEntries	StartIndex	SourceTableListCount	SourceTableList

Figure 2.51 Fields of the Backup_Source_Bind_req Command Frame

Table 2.77 specifies the fields of the Backup_Source_Bind_req command frame.

Table 2.77 Fields of the Backup_Source_Bind_req Command

Name	Type	Valid Range	Description
SourceTableEntries	Integer	0x0000 - 0xffff	Total number of source table entries on the primary binding table cache device.
StartIndex	Integer	0x0000 - 0xffff	Starting index within the binding table of the entries in SourceTableList.
SourceTableListCount	Integer	0x0000 - 0xffff	Number of source table entries included within SourceTableList.
SourceTableList	List of IEEE Addresses	The list shall contain the number of elements given by the SourceTableListCount	A list of addresses beginning with the StartIndex element and continuing for SourceTableListCount of source addresses in the primary binding table cache device's source table.

2.4.3.2.10.1 When Generated

The Backup_Source_Bind_req is generated from a local primary binding table cache and sent to a remote backup binding table cache device to request backup storage of its entire source table. The destination addressing mode for this request is unicast.

2.4.3.2.10.2 Effect on Receipt

If the remote device is not the backup binding table cache, it shall return a status of NOT_SUPPORTED. If it does not recognize the sending device as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall overwrite the source entries in its backup source table starting with StartIndex and continuing for SourceTableListCount entries. If this exceeds its table size, it shall return a status of TABLE_FULL.

Otherwise, it shall return a status of SUCCESS. The command always truncates the backup table to a number of entries equal to its maximum size or SourceTableEntries, whichever is smaller.

2.4.3.2.11 Recover_Source_Bind_req

The Recover_Source_Bind_req command (ClusterID=0x002a) shall be formatted as illustrated in Figure 2.52.



Figure 2.52 Format of the Recover_Source_Bind_req Command Frame

Table 2.78 specifies the fields of the Recover_Source_Bind_req command frame.

Table 2.78 Fields of the Recover_Source_Bind_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x0000 - 0xffff	Starting index for the requested elements of the binding table

2.4.3.2.11.1 When Generated

The Recover_Source_Bind_req is generated from a local primary binding table cache and sent to the remote backup binding table cache device when it wants a complete restore of the source binding table. The destination addressing mode for this request is unicast.

2.4.3.2.11.2 Effect on Receipt

If the remote device is not the backup binding table cache it shall return a status of NOT_SUPPORTED. If it does not recognize the sending device as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall prepare a list of source binding table entries from its backup beginning with StartIndex. It will fit in as many entries as possible into a Recover_Source_Bind_rsp command and return a status of SUCCESS.

2.4.3.3 Network Management Client Services

Table 2.79 lists the commands supported by Device Profile: Network Management Client Services. Each of these primitives will be discussed in the following sub-clauses.

Table 2.79 Network Management Client Services Commands

Network Management Client Services	Client Transmission	Server Processing
Mgmt_NWK_Disc_req	O	O
Mgmt_Lqi_req	O	O
Mgmt_Rtg_req	O	O
Mgmt_Bind_req	O	O
Mgmt_Leave_req	O	O
Mgmt_Direct_Join_req	O	O
Mgmt_Permit_Joining_req	O	M
Mgmt_Cache_req	O	O
Mgmt_NWK_Update_req	O	O

2.4.3.3.1 Mgmt_NWK_Disc_req

The Mgmt_NWK_Disc_req command (ClusterID=0x0030) shall be formatted as illustrated in Figure 2.53.

Octets: 4	1	1
ScanChannels	ScanDuration	StartIndex

Figure 2.53 Format of the Mgmt_NWK_Disc_req Command Frame

Table 2.80 specifies the fields for the Mgmt_NWK_Disc_req command frame.

Table 2.80 Fields of the Mgmt_NWK_Disc_req Command

Name	Type	Valid Range	Description
ScanChannels	Bitmap	32-bit field	See (sub-clause 3.2.2.1) for details on NLME-NETWORK-DISCOVERY.request ScanChannels parameter.
ScanDuration	Integer	0x00-0x0e	A value used to calculate the length of time to spend scanning each channel. The time spent scanning each channel is $(aBaseSuperframeDuration * (2^n + 1))$ symbols, where n is the value of the ScanDuration parameter. For more information on MAC sub-layer scanning (see [B1]).
StartIndex	Integer	0x00-0xff	Starting index within the resulting NLME-NETWORK-DISCOVERY.confirm NetworkList to begin reporting for the Mgmt_NWK_Disc_rsp.

2.4.3.3.1.1 When Generated

The Mgmt_NWK_Disc_req is generated from a Local Device requesting that the Remote Device execute a Scan to report back networks in the vicinity of the Local Device. The destination addressing on this command shall be unicast.

2.4.3.3.1.2 Effect on Receipt

The Remote Device shall execute an NLME-NETWORK-DISCOVERY.request using the ScanChannels and ScanDuration parameters supplied with the Mgmt_NWK_Disc_req command. The results of the Scan shall be reported back to the Local Device via the Mgmt_NWK_Disc_rsp command.

If this command is not supported in the Remote Device, the return status provided with the Mgmt_NWK_Disc_rsp shall be NOT_SUPPORTED. If the scan was successful, the Mgmt_NWK_Disc_rsp command shall contain a status of SUCCESS and the results of the scan shall be reported, beginning with the StartIndex element of the NetworkList. If the scan was unsuccessful, the Mgmt_NWK_Disc_rsp command shall contain the error code reported in the NLME-NETWORK-DISCOVERY.confirm primitive.

2.4.3.3.2 Mgmt_Lqi_req

The Mgmt_Lqi_req command (ClusterID=0x0031) shall be formatted as illustrated in Figure 2.54.



Figure 2.54 Format of the Mgmt_Lqi_req Command Frame

Table 2.81 specifies the fields for the Mgmt_NWK_Disc_req command frame.

Table 2.81 Fields of the Mgmt_Lqi_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x00-0xff	Starting Index for the requested elements of the Neighbor Table.

2.4.3.3.2.1 When Generated

The Mgmt_Lqi_req is generated from a Local Device wishing to obtain a neighbor list for the Remote Device along with associated LQI values to each neighbor. The destination addressing on this command shall be unicast only and the destination address must be that of a ZigBee Coordinator or ZigBee Router.

2.4.3.3.2.2 Effect on Receipt

Upon receipt, a Remote Device (ZigBee Router or ZigBee Coordinator) shall retrieve the entries of the neighbor table and associated LQI values via the NLME-GET.request primitive (for the *nwkNeighborTable* attribute) and report the resulting neighbor table (obtained via the NLME-GET.confirm primitive) via the Mgmt_Lqi_rsp command.

If this command is not supported in the Remote Device, the return status provided with the Mgmt_Lqi_rsp shall be NOT_SUPPORTED. If the neighbor table was obtained successfully, the Mgmt_Lqi_rsp command shall contain a status of SUCCESS and the neighbor table shall be reported, beginning with the element in the list enumerated as StartIndex. If the neighbor table was not obtained successfully, the Mgmt_Lqi_rsp command shall contain the error code reported in the NLME-GET.confirm primitive.

2.4.3.3.3 Mgmt_Rtg_req

The Mgmt_Rtg_req command (ClusterID=0x0032) shall be formatted as illustrated in Figure 2.55.



Figure 2.55 Format of the Mgmt_Rtg_req Command Frame

Table 2.82 specifies the fields for the Mgmt_Rtg_req command frame.

Table 2.82 Fields of the Mgmt_Rtg_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x00-0xff	Starting Index for the requested elements of the Routing Table

2.4.3.3.3.1 When Generated

The Mgmt_Rtg_req is generated from a Local Device wishing to retrieve the contents of the Routing Table from the Remote Device. The destination addressing on this command shall be unicast only and the destination address must be that of the ZigBee Router or ZigBee Coordinator.

2.4.3.3.3.2 Effect on Receipt

Upon receipt, a Remote Device (ZigBee Coordinator or ZigBee Router) shall retrieve the entries of the routing table from the NWK layer via the NLME-GET.request primitive (for the *nwkRouteTable* attribute) and report the resulting routing table (obtained via the NLME-GET.confirm primitive) via the Mgmt_Rtg_rsp command.

If the Remote Device does not support this optional management request, it shall return a Status of NOT_SUPPORTED. If the routing table was obtained successfully, the Mgmt_Rtg_req command shall contain a status of SUCCESS and the routing table shall be reported, beginning with the element in the list enumerated as StartIndex. If the routing table was not obtained successfully, the Mgmt_Rtg_rsp command shall contain the error code reported in the NLME-GET.confirm primitive.

2.4.3.3.4 Mgmt_Bind_req

The Mgmt_Bind_req command (ClusterID=0x0033) shall be formatted as illustrated in Figure 2.56.



Figure 2.56 Format of the Mgmt_Bind_req Command Frame

Table 2.83 specifies the fields for the Mgmt_Bind_req command frame.

Table 2.83 Fields of the Mgmt_Bind_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x00-0xff	Starting Index for the requested elements of the Binding Table.

2.4.3.3.4.1 When Generated

The Mgmt_Bind_req is generated from a Local Device wishing to retrieve the contents of the Binding Table from the Remote Device. The destination addressing on this command shall be unicast only and the destination address must be that of a Primary binding table cache or source device holding its own binding table.

2.4.3.3.4.2 Effect on Receipt

Upon receipt, a Remote Device shall retrieve the entries of the binding table from the APS sub-layer via the APSME-GET.request primitive (for the *apsBindingTable* attribute) and report the resulting binding table (obtained via the APSME-GET.confirm primitive) via the Mgmt_Bind_rsp command.

If the Remote Device does not support this optional management request, it shall return a status of NOT_SUPPORTED. If the binding table was obtained successfully, the Mgmt_Bind_rsp command shall contain a status of SUCCESS and the binding table shall be reported, beginning with the element in the list enumerated as StartIndex. If the binding table was not obtained successfully, the Mgmt_Bind_rsp command shall contain the error code reported in the APSME-GET.confirm primitive.

2.4.3.3.5 Mgmt_Leave_req

The Mgmt_Leave_req command (ClusterID=0x0034) shall be formatted as illustrated in Figure 2.57.

Bits: 64	6	1	1
Device Address	Reserved	Remove Children	Rejoin

Figure 2.57 Format of the Mgmt_Leave_req Command Frame

Table 2.84 specifies the fields for the Mgmt_Leave_req command frame.

Table 2.84 Fields of the Mgmt_Leave_req Command

Name	Type	Valid Range	Description
DeviceAddress	Device Address	An extended 64-bit, IEEE address	See (sub-clause 3.2.2.16) for details on the DeviceAddress parameter within NLME-LEAVE.request. For DeviceAddress of NULL, a value of 0x0000000000000000 shall be used.
Remove Children	Bit	0 or 1	This field has a value of 1 if the device being asked to leave the network is also being asked to remove its child devices, if any. Otherwise, it has a value of 0.
Rejoin	Bit	0 or 1	This field has a value of 1 if the device being asked to leave from the current parent is requested to rejoin the network. Otherwise, it has a value of 0.

2.4.3.3.5.1 When Generated

The Mgmt_Leave_req is generated from a Local Device requesting that a Remote Device leave the network or to request that another device leave the network. The Mgmt_Leave_req is generated by a management application which directs the request to a Remote Device where the NLME-LEAVE.request is to be executed using the parameter supplied by Mgmt_Leave_req.

2.4.3.3.5.2 Effect on Receipt

Upon receipt, the remote device shall issue the NLME-LEAVE.request primitive using the parameters supplied with the Mgmt_Leave_req command. The results of the leave attempt shall be reported back to the local device via the Mgmt_Leave_rsp command.

If the remote device does not support this optional management request, it shall return a status of NOT_SUPPORTED. If the leave attempt was executed

successfully, the Mgmt_Leave_rsp command shall contain a status of SUCCESS. If the leave attempt was not executed successfully, the Mgmt_Leave_rsp command shall contain the error code reported in the NLME-LEAVE.confirm primitive.

This command shall be subject to a permissions check as defined in sub-clause 4.6.3.8. On failure the remote device shall not carry out the command, and shall respond with NOT_AUTHORIZED.

2.4.3.3.6 Mgmt_Direct_Join_req

The Mgmt_Direct_Join_req command (ClusterID=0x0035) shall be formatted as illustrated in Figure 2.58.

Octets: 8	1
Device Address	Capability Information

Figure 2.58 Format of the Mgmt_Direct_Join_req Command Frame

Table 2.85 specifies the fields for the Mgmt_Direct_Join_req command frame.

Table 2.85 Fields of the Mgmt_Direct_Join_req Command

Name	Type	Valid Range	Description
DeviceAddress	Device Address	An extended 64-bit, IEEE address	See sub-clause 3.2.2.14 for details on the DeviceAddress parameter within NLME-DIRECT-JOIN.request.
CapabilityInformation	Bitmap	See Table 3.47	The operating capabilities of the device being directly joined.

2.4.3.3.6.1 When Generated

The Mgmt_Direct_Join_req is generated from a Local Device requesting that a Remote Device permit a device designated by DeviceAddress to join the network directly. The Mgmt_Direct_Join_req is generated by a management application which directs the request to a Remote Device where the NLME-DIRECT-JOIN.request is to be executed using the parameter supplied by Mgmt_Direct_Join_req.

2.4.3.3.6.2 Effect on Receipt

Upon receipt, the remote device shall issue the NLME-DIRECT-JOIN.request primitive using the DeviceAddress and CapabilityInformation parameters supplied with the Mgmt_Direct_Join_req command. The results of the direct join attempt shall be reported back to the local device via the Mgmt_Direct_Join_rsp command.

If the remote device does not support this optional management request, it shall return a status of NOT_SUPPORTED. If the direct join attempt was executed successfully, the Mgmt_Direct_Join_rsp command shall contain a status of SUCCESS. If the direct join attempt was not executed successfully, the Mgmt_Direct_Join_rsp command shall contain the error code reported in the NLME-DIRECT-JOIN.confirm primitive.

This command shall be subject to a permissions check as defined in sub-clause 4.6.3.8. On failure the remote device shall not carry out the command, and shall respond with NOT_AUTHORIZED.

2.4.3.3.7 Mgmt_Permit_Joining_req

The Mgmt_Permit_Joining_req command (ClusterID=0x0036) shall be formatted as illustrated in Figure 2.59.

Octets: 1	1
PermitDuration	TC_Significance

Figure 2.59 Format of the Mgmt_Permit_Joining_req Command Frame

Table 2.86 specifies the fields of the Mgmt_Permit_Joining_req command frame.

Table 2.86 Fields of the Mgmt_Permit_Joining_req Command

Name	Type	Valid Range	Description
PermitDuration	Integer	0x00 - 0xff	See sub-clause 3.2.2.5 for details on the PermitDuration parameter within NLME-PERMIT-JOINING.request.
TC_Significance	Boolean Integer	0x00 - 0x01	If this is set to 0x01 and the remote device is the Trust Center, the command affects the Trust Center authentication policy as described in the sub-clauses below; If this is set to 0x00, there is no effect on the Trust Center.

2.4.3.3.7.1 When Generated

The Mgmt_Permit_Joining_req is generated from a Local Device requesting that a remote device or devices allow or disallow association. The Mgmt_Permit_Joining_req is generated by a management application or commissioning tool which directs the request to a remote device(s) where the NLME-PERMIT-JOINING.request is executed using the PermitDuration parameter supplied by Mgmt_Permit_Joining_req. Additionally, if the remote device is the Trust Center and TC_Significance is set to 1, the Trust Center authentication policy will be affected. The addressing may be unicast or 'broadcast to all routers and coordinator'.

2.4.3.3.7.2 Effect on Receipt

Upon receipt, the remote device(s) shall issue the NLME-PERMIT-JOINING.request primitive using the PermitDuration parameter supplied with the Mgmt_Permit_Joining_req command. If the PermitDuration parameter is not equal to zero or 0xFF, the parameter is a number of seconds and joining is permitted until it counts down to zero, after which time, joining is not permitted. If the PermitDuration is set to zero, joining is not permitted. If set to 0xFF, joining is permitted indefinitely or until another Mgmt_Permit_Joining_req is received. If a second Mgmt_Permit_Joining_req is received while the previous one is still counting down, it will supersede the previous request. Additionally, if the remote device is the Trust Center and TC_Significance is set to 1, the Trust Center authentication policy will be affected. In this case, if PermitDuration is set to a non-zero value, Trust Center authentication is allowed so that when the Trust Center receives an NLME-JOIN.indication or an APSME-UPDATE-DEVICE.indication indicating that a new device has joined, it will authenticate it and issue a security key as appropriate. Alternatively, if PermitDuration is set to zero, Trust Center authentication will be disallowed with the effect that if an APSME-UPDATE-DEVICE.indication is received indicating that a new device has joined, The Trust Center shall then issue an APSME-REMOVE-DEVICE.request to refuse the new device. Note that the TC_Significance flag and the Trust Center action will be subject to the security policy imposed by the stack profile. Particularly, the Trust Center may be configured not to act on this flag unless it has been sent by particular trusted devices such as configuration tools which are known to the Trust Center. Similarly, the main command features may be disallowed under some stack profiles unless the sending device can be authenticated as a known configuration device. If the command is not permitted, a response of INVALID_REQUEST shall be sent (unless the command was a 'broadcast to all routers and coordinator' in which case no response shall be sent) If the Mgmt_Permit_Joining_req primitive was received as a unicast, the results of the NLME-PERMIT-JOINING.request shall be reported back to the local device via the Mgmt_Permit_Joining_rsp command. If the command was received as a broadcast, no response shall be sent back.

This command shall be subject to a permissions check as defined in sub-clause 4.6.3.8. On failure, the remote device shall not carry out the command, and shall respond with NOT_AUTHORIZED if the Mgmt_Permit_Joining_req was received as an unicast, and shall not respond otherwise.

2.4.3.3.8 Mgmt_Cache_req

The Mgmt_Cache_req command (ClusterID=0x0037) shall be formatted as illustrated in Figure 2.60.

Octets: 1
StartIndex

Figure 2.60 Fields of the Mgmt_Cache_req Command Frame

Table 2.87 specifies the fields of the Mgmt_Cache_req command frame.

Table 2.87 Fields of the Mgmt_Cache_req Command

Name	Type	Valid Range	Description
StartIndex	Integer	0x00 - 0xff	Starting Index for the requested elements of the discovery cache list.

2.4.3.3.8.1 When Generated

The Mgmt_Cache_req is provided to enable ZigBee devices on the network to retrieve a list of ZigBee End Devices registered with a Primary Discovery Cache device. The destination addressing on this primitive shall be unicast.

2.4.3.3.8.2 Effect on Receipt

Upon receipt, the Remote Device shall determine whether it is a Primary Discovery Cache or whether this optional request primitive is supported. If it is not a Primary Discovery Cache device or the Mgmt_Cache_req primitive is not supported, the Remote Device shall return a status of NOT_SUPPORTED. If the Remote Device is a Primary Discovery Cache and supports the Mgmt_Cache_req, the Remote Device shall return SUCCESS to the Local Device along with the discovery cache list which consists of the NWKAddr and IEEEAddr for each ZigBee End Device registered.

2.4.3.3.9 Mgmt_NWK_Update_req

The Mgmt_NWK_Update_req command (ClusterID=0x0038) shall be formatted as illustrated in Figure 2.61.

Octets: 4	1	0/1	0/1	0/2
ScanChannels	ScanDuration	ScanCount	<i>nwkUpdateId</i>	<i>nwkManagerAddr</i>

Figure 2.61 Fields of the Mgmt_NWK_Update_req Command Frame

Table 2.88 specifies the fields of the Mgmt_NWK_Update_req command frame.

Table 2.88 Fields of the Mgmt_NWK_Update_req Command

Name	Type	Valid Range	Description
ScanChannels	Bitmap	32-bit field	See (sub-clause 3.2.2.1) for details on NLME-ED-SCAN.request ScanChannels parameter.
ScanDuration	Integer	0x00-0x05 or 0xfe or 0xff	<p>A value used to calculate the length of time to spend scanning each channel. The time spent scanning each channel is $(aBaseSuperframeDuration * (2^n + 1))$ symbols, where n is the value of the ScanDuration parameter. For more information on MAC sub-layer scanning (see [B1]).</p> <p>If ScanDuration has a value of 0xfe this is a request for channel change.</p> <p>If ScanDuration has a value of 0xff this is a request to change the <i>apsChannelMask</i> and <i>nwkManagerAddr</i> attributes.</p>
ScanCount	Integer	0x00 - 0x05	<p>This field represents the number of energy scans to be conducted and reported.</p> <p>This field shall be present only if the ScanDuration is within the range of 0x00 to 0x05.</p>
<i>nwkUpdateId</i>	Integer	0x00 - 0xFF	<p>The value of the <i>nwkUpdateId</i> contained in this request. This value is set by the Network Channel Manager prior to sending the message.</p> <p>This field shall only be present if the ScanDuration is 0xfe or 0xff. If the ScanDuration is 0xff, then the value in the <i>nwkUpdateID</i> shall be ignored.</p>
<i>nwkManagerAddr</i>	Device Address	16-bit NWK address	This field shall be present only if the ScanDuration is set to 0xff, and, where present, indicates the NWK address for the device with the Network Manager bit set in its Node Descriptor.

2.4.3.3.9.1 When Generated

This command is provided to allow updating of network configuration parameters or to request information from devices on network conditions in the local operating environment. The destination addressing on this primitive shall be unicast or broadcast to all devices for which `macRxOnWhenIdle = TRUE`.

2.4.3.3.9.2 Effect on Receipt

Upon receipt, the Remote Device shall determine from the contents of the `ScanDuration` parameter whether this request is an update to the `apsChannelMask` and `nwkManagerAddr` attributes, a channel change command, or a request to scan channels and report the results.

If the `ScanDuration` parameter is equal to `0xfe`, the message is a command to change channels. The receiver shall determine if the channel is one within the range of the current PHY, and if the command has a channel outside that range a response of `INVALID_REQUEST` shall be generated, and the original request shall be dropped and no further processing shall be done. This command provides a new active channel as a single channel in the `ChannelMask` in which case the APS IB is not updated. If the channel is valid for the current PHY then the procedure for channel change shall be initiated.¹²

If the `ScanDuration` parameter is equal to `0xff`, the command provides a set of new `apsChannelMask` along with a new `nwkManagerAddr`. The Remote Device shall store the `apsChannelMask` in the APS IB and the `nwkManagerAddr` in the NIB without invocation of an `NLME-ED-SCAN.request`.

If this command is unicast with `ScanDuration` set to `0xfe` or `0xff`, the Remote Device shall not respond. The network manager should request an APS acknowledgement in this case.

If the `ScanDuration` is equal to `0x00` to `0x05` and the destination addressing on this command was unicast then the command is interpreted as a request to scan the channels described in `ChannelMask`. If the channel mask contains a channel outside the range of the current PHY, then a response of `INVALID_REQUEST` shall be sent back. Otherwise the device shall use the parameter `ScanDuration` and `ScanCount`, via invocation of an `NLME-ED-SCAN.request`.¹³ If the Remote Device does not support fragmentation and the resulting response will exceed the APDU, the Remote Device shall perform the Energy Detect Scan on as many of the requested channels as will fit into a single APDU, highlighting the list of actual scanned channels in the response parameter. If multiple scans are requested in the `ScanCount`, each scan is reported as a separate result. The Remote Device will employ an Energy Detect Scan using the request parameters, modified by the

12. ZigBee Document 12-0220-04

13. ZigBee Document 12-0220-04

limitation described for fragmentation, and supply the results to the requesting device with a Mgmt_NWK_Update_notify with a SUCCESS status.

Otherwise, if the ScanDuration is equal to 0x06 to 0xfd and the destination addressing on this command was unicast then the Remote Device shall return a status of INVALID_REQUEST.

If the destination addressing on this command was not unicast then the Remote Device shall not transmit a response.

2.4.4 Server Services

The Device Profile Server Services support the processing of device and service discovery requests, end device bind requests, bind requests, unbind requests, and network management requests. Additionally, Server Services support transmission of these responses back to the requesting device.

For all broadcast addressed requests (of any broadcast address type) to the server, if the command is not supported, the server shall drop the packet. No error status shall be unicast back to the Local Device for any broadcast addressed client request including, but not limited to, requests which are not supported on the server.

For all unicast addressed requests to the server, if the command is not supported, the server shall formulate a response packet including the response Cluster ID and status fields only. The response Cluster ID shall be created by taking the request Cluster ID and setting the high order bit to create the response Cluster ID. The status field shall be set to NOT_SUPPORTED. The resulting response shall be unicast to the requesting client.

2.4.4.1 Device and Service Discovery Server

Table 2.89 lists the commands supported by the Device and Service Discovery Server Services device profile. Each of these commands will be discussed in the following sub-clauses. For receipt of the Device_annce command, the server shall check all internal references to the IEEE and 16-bit NWK addresses supplied in the request. For all references to the IEEE address in the Local Device, the corresponding NWK address supplied in the Device_annce shall be substituted. For any other references to the NWK address in the Local Device, the

corresponding entry shall be marked as not having a known valid 16-bit NWK address. The server shall not supply a response to the Device_annce.

Table 2.89 Device and Service Discovery Server Service Primitives

Device and Service Discovery Server Services	Server Processing
NWK_addr_rsp	M
IEEE_addr_rsp	M
Node_Desc_rsp	M
Power_Desc_rsp	M
Simple_Desc_rsp	M
Active_EP_rsp	M
Match_Desc_rsp	M
Complex_Desc_rsp	O
User_Desc_rsp	O
User_Desc_conf	O
System_Server_Discovery_rsp	O
Discovery_store_rsp	O
Node_Desc_store_rsp	O
Power_Desc_store_rsp	O
Active_EP_store_rsp	O
Simple_Desc_store_rsp	O
Remove_node_cache_rsp	O
Find_node_cache_rsp	O
Extended_Simple_Desc_rsp	O
Extended_Active_EP_rsp	O

2.4.4.1.1 NWK_addr_rsp

The NWK_addr_rsp command (ClusterID=0x8000) shall be formatted as illustrated in Figure 2.62.

Octets: 1	8	2	0/1	0/1	Variable
Status	IEEEAddr RemoteDev	NWKAddr RemoteDev	Num AssocDev	StartIndex	NWKAddr AssocDevList

Figure 2.62 Format of the NWK_addr_rsp Command Frame

Table 2.90 specifies the fields of the NWK_addr_rsp command frame.

Table 2.90 Fields of the NWK_addr_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INV_REQUESTTYPE or DEVICE_NOT_FOUND	The status of the NWK_addr_req command.
IEEEAddrRemoteDev	Device Address	An extended 64-bit, IEEE address	64-bit address for the Remote Device.
NWKAddrRemoteDev	Device Address	A 16-bit, NWK address	16-bit address for the Remote Device.
NumAssocDev	Integer	0x00-0xff	Count of the number of 16-bit short addresses to follow. If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall be set to 0. If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame.
StartIndex	Integer	0x00-0xff	Starting index into the list of associated devices for this report. If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall not be included in the frame. If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame.

Table 2.90 Fields of the NWK_addr_rsp Command (Continued)

Name	Type	Valid Range	Description
NWKAddrAssocDevList	Device Address List	List of NumAssocDev 16-bit short addresses, each with range 0x0000 - 0xffff	<p>A list of 16-bit addresses, one corresponding to each associated device to Remote Device; The number of 16-bit network addresses contained in this field is specified in the NumAssocDev field.</p> <p>If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall not be included in the frame.</p> <p>If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame.</p>

2.4.4.1.1.1 When Generated

The NWK_addr_rsp is generated by a Remote Device in response to a NWK_addr_req command inquiring as to the NWK address of the Remote Device or the NWK address of an address held in a local discovery cache (see sub-clause 2.4.3.1.1.2 for a detailed description). The destination addressing on this command is unicast.

2.4.4.1.1.2 Effect on Receipt

On receipt of the NWK_addr_rsp command, the recipient is either notified of the status of its attempt to discover a NWK address from an IEEE address or notified of an error. If the NWK_addr_rsp command is received with a Status of SUCCESS, the remaining fields of the command contain the appropriate discovery information, according to the RequestType as specified in the original NWK_Addr_req command. Otherwise, the Status field indicates the error and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included.

2.4.4.1.2 IEEE_addr_rsp

The IEEE_addr_rsp command (ClusterID=0x8001) shall be formatted as illustrated in Figure 2.63.

Octets: 1	8	2	0/1	0/1	Variable
Status	IEEEAddrRemoteDev	NWKAddrRemoteDev	NumAssocDev	StartIndex	NWKAddrAssocDevList

Figure 2.63 Format of the IEEE_addr_rs Command Frame

Table 2.91 specifies the fields of the IEEE_addr_rs command frame.

Table 2.91 IEEE_addr_rsp Parameters

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INV_REQUESTTYPE or DEVICE_NOT_FOUND	The status of the IEEE_addr_req command.
IEEEAddrRemoteDev	Device Address	An extended 64-bit, IEEE address	64-bit address for the Remote Device.
NWKAddrRemoteDev	Device Address	A 16-bit, NWK address	16-bit address for the Remote Device.
NumAssocDev	Integer	0x00-0xff	Count of the number of 16-bit short addresses to follow. If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall be set to 0. If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame.

Table 2.91 IEEE_addr_rsp Parameters (Continued)

Name	Type	Valid Range	Description
StartIndex	Integer	0x00-0xff	Starting index into the list of associated devices for this report. If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall not be included in the frame. If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame.
NWKAddrAssocDevList	Device Address List	List of NumAssocDev 16-bit short addresses, each with range 0x0000 - 0xffff	A list of 16-bit addresses, one corresponding to each associated device to Remote Device; The number of 16-bit network addresses contained in this field is specified in the NumAssocDev field. If the RequestType in the request is Extended Response and there are no associated devices on the Remote Device, this field shall not be included in the frame. If an error occurs or the RequestType in the request is for a Single Device Response, this field shall not be included in the frame

2.4.4.1.2.1 When Generated

The IEEE_addr_rsp is generated by a Remote Device in response to an IEEE_addr_req command inquiring as to the 64-bit IEEE address of the Remote Device or the 64-bit IEEE address of an address held in a local discovery cache (see sub-clause 2.4.3.1.2.2 for a detailed description). The destination addressing on this command shall be unicast.

2.4.4.1.2.2 Effect on Receipt

On receipt of the IEEE_addr_rsp command, the recipient is either notified of the status of its attempt to discover an IEEE address from an NWK address or notified of an error. If the IEEE_addr_rsp command is received with a Status of SUCCESS, the remaining fields of the command contain the appropriate discovery information, according to the RequestType as specified in the original IEEE_Addr_req command. Otherwise, the Status field indicates the error and the NumAssocDev, StartIndex, and NWKAddrAssocDevList fields shall not be included.

2.4.4.1.3 Node_Desc_rsp

The Node_Desc_rsp command (ClusterID=0x8002) shall be formatted as illustrated in Figure 2.64.

Octets: 1	2	See sub-clause 2.3.2.3
Status	NWKAddrOfInterest	Node Descriptor

Figure 2.64 Format of the Node_Desc_rsp Command Frame

Table 2.92 specifies the fields of the Node_Desc_rsp command frame.

Table 2.92 Fields of the Node_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Node_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
NodeDescriptor	Node Descriptor		See the Node Descriptor format in sub-clause 2.3.2.3. This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.4.1.3.1 When Generated

The Node_Desc_rsp is generated by a remote device in response to a Node_Desc_req directed to the remote device. This command shall be unicast to the originator of the Node_Desc_req command.

The remote device shall generate the Node_Desc_rsp command using the format illustrated in Table 2.92. The NWKAddrOfInterest field shall match that specified in the original Node_Desc_req command. If the NWKAddrOfInterest field matches the network address of the remote device, it shall set the Status field to SUCCESS and include its node descriptor (see sub-clause 2.3.2.3) in the NodeDescriptor field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE and not include the NodeDescriptor field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND and not include the NodeDescriptor field. If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a node descriptor for that device is available. If a node descriptor is not available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR and not include the NodeDescriptor field. If a node descriptor is available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to SUCCESS and include the node descriptor (see sub-clause 2.3.2.3) of the matching child device in the NodeDescriptor field.

2.4.4.1.3.2 Effect on Receipt

On receipt of the Node_Desc_rsp command, the recipient is either notified of the node descriptor of the remote device indicated in the original Node_Desc_req command or notified of an error. If the Node_Desc_rsp command is received with a Status of SUCCESS, the NodeDescriptor field shall contain the requested node descriptor. Otherwise, the Status field indicates the error and the NodeDescriptor field shall not be included.

2.4.4.1.4 Power_Desc_rsp

The Power_Desc_rsp command (ClusterID=0x8003) shall be formatted as illustrated in Figure 2.65.

Octet: 1	2	Variable
Status	NWKAddr OfInterest	Power Descriptor

Figure 2.65 Format of the Power_Desc_rsp Command Frame

Table 2.93 specifies the fields of the Power_Desc_rsp command frame.

Table 2.93 Fields of the Power_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Power_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
PowerDescriptor	Power Descriptor		See the Node Power Descriptor format in sub- clause 2.3.2.4. This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.4.1.4.1 When Generated

The Power_Desc_rsp is generated by a remote device in response to a Power_Desc_req directed to the remote device. This command shall be unicast to the originator of the Power_Desc_req command.

The remote device shall generate the Power_Desc_rsp command using the format illustrated in Table 2.93. The NWKAddrOfInterest field shall match that specified in the original Power_Desc_req command. If the NWKAddrOfInterest field matches the network address of the remote device, it shall set the Status field to SUCCESS and include its power descriptor (see sub-clause 2.3.2.4) in the PowerDescriptor field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE and not include the PowerDescriptor field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND and not include the PowerDescriptor field. If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a power descriptor for that device is available. If a power descriptor is not available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR and not include the PowerDescriptor field. If a power descriptor is available for the child indicated by the NWKAddrOfInterest field,

the remote device shall set the Status field to SUCCESS and include the power descriptor (see sub-clause 2.3.2.4) of the matching child device in the PowerDescriptor field.

2.4.4.1.4.2 Effect on Receipt

On receipt of the Power_Desc_rsp command, the recipient is either notified of the power descriptor of the remote device indicated in the original Power_Desc_req command or notified of an error. If the Power_Desc_rsp command is received with a Status of SUCCESS, the PowerDescriptor field shall contain the requested power descriptor. Otherwise, the Status field indicates the error and the PowerDescriptor field shall not be included.

2.4.4.1.5 Simple_Desc_rsp

The Simple_Desc_rsp command (ClusterID=0x8004) shall be formatted as illustrated in Figure 2.66.

Octet: 1	2	1	Variable
Status	NWKAddr OfInterest	Length	Simple Descriptor

Figure 2.66 Format of the Simple_Desc_rsp Command Frame

Table 2.94 specifies the fields of the Simple_Desc_rsp command frame.

Table 2.94 Fields of the Simple_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INVALID_EP, NOT_ACTIVE, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Simple_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Length	Integer	0x00-0xff	Length in bytes of the Simple Descriptor to follow.
SimpleDescriptor	Simple Descriptor		See the Simple Descriptor format in sub-clause 2.3.2.5. This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.4.1.5.1 When Generated

The Simple_Desc_rsp is generated by a remote device in response to a Simple_Desc_req directed to the remote device. This command shall be unicast to the originator of the Simple_Desc_req command.

The remote device shall generate the Simple_Desc_rsp command using the format illustrated in Table 2.94. The NWKAddrOfInterest field shall match that specified in the original Simple_Desc_req command. If the endpoint field specified in the original Simple_Desc_req command does not fall within the correct range specified in Table 2.49, the remote device shall set the Status field to INVALID_EP, set the Length field to 0 and not include the SimpleDescriptor field.

If the NWKAddrOfInterest field matches the network address of the remote device, it shall determine whether the endpoint field specifies the identifier of an active endpoint on the device. If the endpoint field corresponds to an active endpoint, the remote device shall set the Status field to SUCCESS, set the Length field to the length of the simple descriptor on that endpoint, and include the simple descriptor (see sub-clause 2.3.2.5) for that endpoint in the SimpleDescriptor field. If the endpoint field does not correspond to an active endpoint, the remote device shall set the Status field to NOT_ACTIVE, set the Length field to 0, and not include the SimpleDescriptor field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the Length field to 0, and not include the SimpleDescriptor field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND, set the Length field to 0, and not include the SimpleDescriptor field.

If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a simple descriptor for that device and on the requested endpoint is available. If a simple descriptor is not available on the requested endpoint of the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR, set the Length field to 0, and not include the SimpleDescriptor field. If a simple descriptor is available on the requested endpoint of the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to SUCCESS, set the Length field to the length of the simple descriptor on that endpoint, and include the simple descriptor (see sub-clause 2.3.2.5) for that endpoint of the matching child device in the SimpleDescriptor field.

2.4.4.1.5.2 Effect on Receipt

On receipt of the Simple_Desc_rsp command, the recipient is either notified of the simple descriptor on the endpoint of the remote device indicated in the original Simple_Desc_req command or notified of an error. If the Simple_Desc_rsp command is received with a Status of SUCCESS, the SimpleDescriptor field shall contain the requested simple descriptor. Otherwise, the Status field indicates the error and the SimpleDescriptor field shall not be included.

2.4.4.1.6 Active_EP_rsp

The Active_EP_rsp command (ClusterID=0x8005) shall be formatted as illustrated in Figure 2.67.

Octet: 1	2	1	Variable
Status	NWKAddrOfInterest	ActiveEPCount	ActiveEPList

Figure 2.67 Format of the Active_EP_rsp Command Frame

Table 2.95 specifies the fields of the Active_EP_rsp command frame.

Table 2.95 Fields of the Active_EP_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND , INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Active_EP_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
ActiveEPCount	Integer	0x00-0xff	The count of active endpoints on the Remote Device.
ActiveEPList			List of bytes each of which represents an 8-bit endpoint.

2.4.4.1.6.1 When Generated

The Active_EP_rsp is generated by a remote device in response to an Active_EP_req directed to the remote device. This command shall be unicast to the originator of the Active_EP_req command.

The remote device shall generate the Active_EP_rsp command using the format illustrated in Table 2.95. The NWKAddrOfInterest field shall match that specified in the original Active_EP_req command. If the NWKAddrOfInterest field matches the network address of the remote device, it shall set the Status field to SUCCESS, set the ActiveEPCount field to the number of active endpoints on that

device and include an ascending list of all the identifiers of the active endpoints on that device in the ActiveEPList field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of a device it holds in a discovery cache. If the NWKAddrOfInterest field does not match the network address of a device it holds in a discovery cache, it shall set the Status field to DEVICE_NOT_FOUND, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the NWKAddrOfInterest matches the network address of a device held in a discovery cache on the remote device, it shall determine whether that device has any active endpoints. If the discovery information corresponding to the ActiveEP request has not yet been uploaded to the discovery cache, the remote device shall set the Status field to NO_DESCRIPTOR, set the ActiveEPCount field to 0 and not include the ActiveEPList field. If the cached device has no active endpoints, the remote device shall set the Status field to SUCCESS, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the cached device has active endpoints, the remote device shall set the Status field to SUCCESS, set the ActiveEPCount field to the number of active endpoints on that device, and include an ascending list of all the identifiers of the active endpoints on that device in the ActiveEPList field.

2.4.4.1.6.2 Effect on Receipt

On receipt of the Active_EP_rsp command, the recipient is either notified of the active endpoints of the remote device indicated in the original Active_EP_req command or notified of an error. If the Active_EP_rsp command is received with a Status of SUCCESS, the ActiveEPCount field indicates the number of entries in the ActiveEPList field. Otherwise, the Status field indicates the error and the ActiveEPList field shall not be included.

2.4.4.1.7 Match_Desc_rsp

The Match_Desc_rsp command (ClusterID=0x8006) shall be formatted as illustrated in Figure 2.68.

Octet: 1	2	1	Variable
Status	NWKAddr OfInterest	Match Length	Match List

Figure 2.68 Format of the Match_Desc_rsp Command Frame

Table 2.96 specifies the fields of the Match_Desc_rsp command frame.

Table 2.96 Fields of the Match_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Match_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
MatchLength	Integer	0x00-0xff	The count of endpoints on the Remote Device that match the request criteria.
MatchList			List of bytes each of which represents an 8-bit endpoint.

2.4.4.1.7.1 When Generated

The Match_Desc_rsp is generated by a remote device in response to a Match_Desc_req either broadcast or directed to the remote device. This command shall be unicast to the originator of the Match_Desc_req command.

The remote device shall generate the Match_Desc_rsp command using the format illustrated in Table 2.96. If the NWKAddrOfInterest field of the original Match_Desc_req was equal to the broadcast network address for all devices for which macRxOnWhenIdle = TRUE (0xffffd), the remote device shall apply the match criterion, as described below, that was specified in the original Match_Desc_req command to each of its simple descriptors. If the remote device is the coordinator or a router, it shall also apply the match criterion, as described below, to each simple descriptor that it may have obtained from each of its children.

If the NWKAddrOfInterest field of the original Match_Desc_req was not equal to the broadcast network address for all devices for which macRxOnWhenIdle = TRUE (0xffffd), the remote device shall set the NWKAddrOfInterest field to the same network address that was specified in the original Match_Desc_req command.

If the NWKAddrOfInterest field matches the network address of the remote device, it shall apply the match criterion, as described below, that was specified in the original Match_Desc_req command to each of its simple descriptors.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the MatchLength field to 0, and not include the MatchList field. If the NWKAddrOfInterest field does not match the network

address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND, set the MatchLength field to 0, and not include the MatchList field.

If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether any simple descriptors for that device are available. If no simple descriptors are available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR, set the MatchLength field to 0, and not include the MatchList field. If any simple descriptors are available for the child indicated by the NWKAddrOfInterest field, the remote device shall apply the match criterion, as described below, that was specified in the original Match_Desc_req command to each of these simple descriptors.

The remote device shall apply the match criteria to each simple descriptor (see sub-clause 2.3.2.5) as follows. The remote device shall first check if the ProfileID field matches exactly the application profile identifier field of the simple descriptor. If the profileID field does not match exactly the remote device shall check if the Profile ID of the Match_desc_req matches the wildcard profile (0xFFFF) and the Profile ID of the Simple Descriptor is within the Standard range (a public profile) as dictated by document [B25].¹⁴ If the profile identifiers do not match, the remote device shall assume the match to be unsuccessful and perform no further matching.

If the profile identifiers match, the remote device shall determine whether the match criteria contains a list of input clusters (the NumInClusters field is not equal to 0). If the match criteria contains a list of input clusters, the remote device shall check that at least one of the cluster identifiers listed in the InClusterList field matches one of the cluster identifiers in the application input cluster list field of the simple descriptor. If at least one matching input cluster is found, the remote device shall assume the match to be successful, note the identifier of the endpoint to which this simple descriptor refers and perform no further matching.

If the remote device is unable to find any matching input clusters, it shall determine whether the match criterion contains a list of output clusters (the NumOutClusters field is not equal to 0). If the match criterion contains a list of output clusters, the remote device shall check that at least one of the cluster identifiers listed in the OutClusterList field matches one of the cluster identifiers in the application output cluster list field of the simple descriptor. If at least one matching output cluster is found, the remote device shall assume the match to be successful and note the identifier of the endpoint to which this simple descriptor

14. CCB 1224

refers. If the remote device is unable to find any output matching clusters, it shall assume the match to be unsuccessful.

If the above procedure produces one or more matches, the remote device shall construct a separate `Match_Desc_rsp` command for each matching device (including itself). For each response, the Status field shall be set to SUCCESS, the `NWKAddrOfInterest` field shall be set to the address of the appropriate matching device, the `MatchLength` field shall be set to the number of simple descriptors that matched the criteria for the appropriate matching device, and the `MatchList` field shall contain an ascending list of the endpoints on which a simple descriptor matched the criteria for the appropriate matching device.

2.4.4.1.7.2 Effect on Receipt

On receipt of the `Match_Desc_rsp` command, the recipient is either notified of the results of its match criterion query indicated in the original `Match_Desc_req` command or notified of an error. If the `Match_Desc_rsp` command is received with a Status of SUCCESS, the `MatchList` field shall contain the list of endpoints containing simple descriptors that matched the criterion. Otherwise, the Status field indicates the error and the `MatchList` field shall not be included.

2.4.4.1.8 Complex_Desc_rsp

The `Complex_Desc_rsp` command (`ClusterID=0x8010`) shall be formatted as illustrated in Figure 2.69.

Octet: 1	2	1	Variable
Status	NWKAddr OfInterest	Length	Complex Descriptor

Figure 2.69 Format of the `Complex_Desc_rsp` Command Frame

Table 2.97 specifies the fields of the `Complex_Desc_rsp` command frame.

Table 2.97 Fields of the `Complex_Desc_rsp` Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, ^a DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the <code>Complex_Desc_req</code> command.

Table 2.97 Fields of the Complex_Desc_rsp Command

NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Length	Integer	0x00-0xff	Length in bytes of the ComplexDescriptor field.
ComplexDescriptor	Complex Descriptor or		See the Complex Descriptor format in sub-clause 2.3.2.6. This field shall only be included in the frame if the status field is equal to SUCCESS.

a. CCB 1375

2.4.4.1.8.1 When Generated

The Complex_Desc_rsp is generated by a remote device in response to a Complex_Desc_req directed to the remote device. This command shall be unicast to the originator of the Complex_Desc_req command.

The remote device shall generate the Complex_Desc_rsp command using the format illustrated in Table 2.97. The NWKAddrOfInterest field shall match that specified in the original Complex_Desc_req command. If the NWKAddrOfInterest field matches the network address of the remote device but a complex descriptor does not exist, it shall set the Status field to NOT_SUPPORTED, set the Length field to 0, and not include the ComplexDescriptor field. If the NWKAddrOfInterest field matches the network address of the remote device and a complex descriptor exists, it shall set the Status field to SUCCESS, set the Length field to the length of the complex descriptor, and include its complex descriptor (see sub-clause 2.3.2.6) in the ComplexDescriptor field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the Length field to 0, and not include the ComplexDescriptor field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND, set the Length field to 0, and not include the ComplexDescriptor field. If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a complex descriptor for that device is available. If a complex descriptor is not available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR, set the Length field to 0,

and not include the ComplexDescriptor field. If a complex descriptor is available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to SUCCESS, set the Length field to the length of the complex descriptor for that device, and include the complex descriptor (see subclause 2.3.2.6) of the matching child device in the ComplexDescriptor field.

2.4.4.1.8.2 Effect on Receipt

On receipt of the Complex_Desc_rsp command, the recipient is either notified of the complex descriptor of the remote device indicated in the original Complex_Desc_req command or notified of an error. If the Complex_Desc_rsp command is received with a Status of SUCCESS, the ComplexDescriptor field shall contain the requested complex descriptor. Otherwise, the Status field indicates the error and the ComplexDescriptor field shall not be included.

2.4.4.1.9 User_Desc_rsp

The User_Desc_rsp command (ClusterID=0x8011) shall be formatted as illustrated in Figure 2.70.

Octet: 1	2	1	Variable
Status	NWKAddrOfInterest	Length	User Descriptor

Figure 2.70 Format of the User_Desc_rsp Command Frame

Table 2.98 specifies the fields of the User_Desc_rsp command frame.

Table 2.98 Fields of the User_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the User_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Length	Integer	0x00-0x10	Length in bytes of the UserDescriptor field.
UserDescriptor	User Descriptor		See the User Descriptor format in subclause 2.3.2.7. This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.4.1.9.1 When Generated

The User_Desc_rsp is generated by a remote device in response to a User_Desc_req directed to the remote device. This command shall be unicast to the originator of the User_Desc_req command.

The remote device shall generate the User_Desc_rsp command using the format illustrated in Table 2.98. The NWKAddrOfInterest field shall match that specified in the original User_Desc_req command. If the NWKAddrOfInterest field matches the network address of the remote device but a user descriptor does not exist, it shall set the Status field to NO_DESCRIPTOR, set the Length field to 0, and not include the UserDescriptor field. If the NWKAddrOfInterest field matches the network address of the remote device and a user descriptor exists, it shall set the Status field to SUCCESS, set the Length field to the length of the user descriptor, and include its user descriptor (see sub-clause 2.3.2.7) in the UserDescriptor field.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the Length field to 0, and not include the UserDescriptor field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND, set the Length field to 0, and not include the UserDescriptor field. If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a user descriptor for that device is available. If a user descriptor is not available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR, set the Length field to 0, and not include the UserDescriptor field. If a user descriptor is available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to SUCCESS, set the Length field to the length of the user descriptor for that device, and include the user descriptor (see sub-clause 2.3.2.7) of the matching child device in the UserDescriptor field.

2.4.4.1.9.2 Effect on Receipt

On receipt of the User_Desc_rsp command, the recipient is either notified of the user descriptor of the remote device indicated in the original User_Desc_req command or notified of an error. If the User_Desc_rsp command is received with a Status of SUCCESS, the UserDescriptor field shall contain the requested user descriptor. Otherwise, the Status field indicates the error and the UserDescriptor field shall not be included.

2.4.4.1.10 System_Server_Discovery_rsp

The System_Server_Discovery_rsp command (ClusterID=0x8015) shall be formatted as illustrated in Figure 2.75.

Octet: 1	2
Status	ServerMask

Figure 2.71 System_Server_Discovery_rsp Command Frame

Table 2.99 specifies the fields of the System_Server_Discovery_rsp command frame.

Table 2.99 Fields of the System_Server_Discovery_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS	The status of the System_Server_Discovery_rsp command.
ServerMask	Integer	Bitmap	See Table 2.32 for bit assignments.

2.4.4.1.10.1 When Generated

The System_Server_Discovery_rsp is generated from Remote Devices on receipt of a System_Server_Discovery_req primitive if the parameter matches the Server Mask field in its node descriptor. If there is no match, the System_Server_Discovery_req shall be ignored and no response given. Matching is performed by masking the ServerMask parameter of the System_Server_Discovery_req with the Server Mask field in the node descriptor. This command shall be unicast to the device which sent System_Server_Discovery_req with Acknowledge request set in TxOptions. The parameter ServerMask contains the bits in the parameter of the request which match the server mask in the node descriptor.

2.4.4.1.10.2 Effect on Receipt

The requesting device is notified that this device has some of the system server functionality that the requesting device is seeking.

If the Network Manager bit was set in the System_Server_Discovery_rsp, then the Remote Device's NWK address shall be set into the *nwkManagerAddr* of the NIB.

2.4.4.1.11 User_Desc_conf

The User_Desc_conf command (ClusterID=0x8014) shall be formatted as illustrated in Figure 2.72.

Octets: 1	2
Status	NWKAddrOfInterest

Figure 2.72 Format of the User_Desc_conf Command Frame

Table 2.100 specifies the fields of the User_Desc_conf command frame.

Table 2.100 Fields of the User_Desc_conf Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the User_Desc_set command.
NWKAddrOfInterest	Device Address	Any 16-bit NWK address	The network address of the device on which the user descriptor set attempt was made.

2.4.4.1.11.1 When Generated

The User_Desc_conf is generated by a remote device in response to a User_Desc_set directed to the remote device. This command shall be unicast to the originator of the User_Desc_set command.

The remote device shall generate the User_Desc_conf command using the format illustrated in Table 2.100. The NWKAddrOfInterest field shall match that specified in the original User_Desc_set command. If the NWKAddrOfInterest field matches the network address of the remote device but a user descriptor does not exist, it shall set the Status field to NOT_SUPPORTED. If the NWKAddrOfInterest field matches the network address of the remote device and a user descriptor exists, it shall set the Status field to SUCCESS and configure the user descriptor with the ASCII character string specified in the original User_Desc_set command.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of one of its children. If the NWKAddrOfInterest field does not match the network

address of one of the children of the remote device, it shall set the Status field to DEVICE_NOT_FOUND. If the NWKAddrOfInterest matches the network address of one of the children of the remote device, it shall determine whether a user descriptor for that device is available. If a user descriptor is not available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to NO_DESCRIPTOR. If a user descriptor is available for the child indicated by the NWKAddrOfInterest field, the remote device shall set the Status field to SUCCESS and configure the user descriptor with the ASCII character string specified in the original User_Desc_set command.

2.4.4.1.11.2 Effect on Receipt

The local device is notified of the results of its attempt to configure the user descriptor on a remote device.

2.4.4.1.12 Discovery_Cache_rsp

The Discovery_Cache_rsp command (ClusterID=0x8012) shall be formatted as illustrated in Figure 2.73.

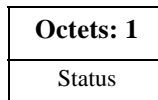


Figure 2.73 Format of the Discovery_Cache_rsp Command Frame

Table 2.101. specifies the fields of the Discovery_Cache_rsp Command Frame.

Table 2.101 Fields of the Discovery_Cache_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS	The status of the Discovery_Cache_req command.

2.4.4.1.12.1 When Generated

The Discovery_Cache_rsp is generated by Primary Discovery Cache devices receiving the Discovery_Cache_req. Remote Devices which are not Primary Discovery Cache devices (as designated in its Node Descriptor) should not respond to the Discovery_Cache_req command.

2.4.4.1.12.2 Effect on Receipt

Upon receipt of the Discovery_Cache_rsp, the Local Device determines if a SUCCESS status was returned. If no Discovery_Cache_rsp messages were returned from the original Discovery_Cache_req command, then the Local Device should increase the radius for the request to locate Primary Discovery Cache devices beyond the radius supplied in the previous request. If a SUCCESS status

is returned, the Local Device should use the Discovery_Store_req, targeted to the Remote Device supplying the response, to determine whether sufficient discovery cache storage is available.

2.4.4.1.13 Discovery_store_rsp

The Discovery_store_rsp command (ClusterID=0x8016) shall be formatted as illustrated in Figure 2.74.

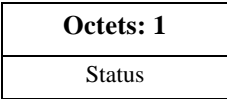


Figure 2.74 Format of the Discovery_store_rsp Command Frame

Table 2.102 specifies the fields of the Discovery_store_rsp command frame

Table 2.102 Fields of the Discovery_store_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INSUFFICIENT_SPACE or NOT_SUPPORTED	The status of the Discovery_store_req command.

2.4.4.1.13.1 When Generated

The Discovery_store_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has space to store the discovery cache data for the Local Device), whether the request is unsupported (meaning the Remote Device is not a Primary Discovery Cache device), or insufficient space exists.

2.4.4.1.13.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should process any other Discovery_store_rsp devices from other Remote Devices or re-perform the Discovery_Cache_req to determine the address of another Primary Discovery Cache device (eliminating the address of the Remote Device that responded with NOT_SUPPORTED if it responds again to the Discovery_Cache_req). If an INSUFFICIENT_SPACE status is returned, the Local Device should also process any other Discovery_store_rsp and re-perform the Discovery_Cache_req if none of the responses indicate SUCCESS (with the radius field increased to include more Remote Devices). If a SUCCESS status is returned, the Local Device shall upload its discovery cache information to the

Remote Device via the Node_Desc_store_req, Power_Desc_store_req, Active_EP_store_req, and Simple_Desc_store_req.

2.4.4.1.14 Node_Desc_store_rsp

The Node_Desc_store_rsp command (ClusterID=0x8017) shall be formatted as illustrated in Figure 2.75.

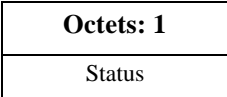


Figure 2.75 Format of the Node_Desc_store_rsp Command Frame

Table 2.103 specifies the fields of the Node_Desc_store_rsp command frame.

Table 2.103 Fields of the Node_Desc_store_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INSUFFICIENT_SPACE, NOT_PERMITTED or NOT_SUPPORTED	The status of the Node_store_rsp command.

2.4.4.1.14.1 When Generated

The Node_store_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has space to store the discovery cache data for the Local Device), whether the request is not supported (meaning the Remote Device is not a Primary Discovery Cache device), or insufficient space exists.

2.4.4.1.14.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should re-perform discovery of the Primary Discovery Cache device. If a NOT_PERMITTED status is returned, the local device must first issue a Discovery_store_req with a returned SUCCESS status. If an INSUFFICIENT_SPACE status is returned, the Local Device shall also send the Remote Device a Remove_node_cache_req. If a SUCCESS status is returned, the Local Device should continue to upload its remaining discovery cache information to the Remote Device via the Power_Desc_store_req, Active_EP_store_req, and Simple_Desc_store_req.

2.4.4.1.15 Power_Desc_store_rsp

The Power_Desc_store_rsp command (ClusterID=0x8018) shall be formatted as illustrated in Figure 2.76.

Octets: 1	8	Variable
Status	IEEEAddr	PowerDescriptor

Figure 2.76 Format of the Power_Desc_store_rsp Command Frame

Table 2.104 specifies the fields of the Power_Desc_store_rsp command frame.

Table 2.104 Fields of the Power_Desc_store_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INSUFFICIENT_SPACE, NOT_PERMITTED or NOT_SUPPORTED	The status of the Power_store_rsp command.

2.4.4.1.15.1 When Generated

The Power_Desc_store_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has space to store the discovery cache data for the Local Device), whether the request is not supported (meaning the Remote Device is not a Primary Discovery Cache device), or insufficient space exists.

2.4.4.1.15.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should re-perform discovery on the Primary Discovery Cache. If a NOT_PERMITTED status is returned, the local device must first issue a Discovery_store_req with a returned SUCCESS status. If an INSUFFICIENT_SPACE status is returned, the Local Device shall discontinue upload of discovery information, issue a Remove_node_cache_req (citing the Local Device), and cease attempts to upload discovery information to the Remote Device.

If a SUCCESS status is returned, the Local Device should continue to upload its remaining discovery cache information to the Remote Device via the Active_EP_store_req and Simple_Desc_store_req.

2.4.4.1.16 Active_EP_store_rsp

The Active_EP_store_rsp command (ClusterID=0x8019) shall be formatted as illustrated in Figure 2.77.

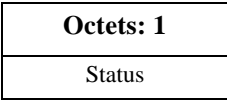


Figure 2.77 Format of the Active_EP_store_rsp Command Frame

Table 2.105 specifies the fields of the Active_EP_store_rsp command frame.

Table 2.105 Fields of the Active_EP_store_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INSUFFICIENT_SPACE, NOT_PERMITTED or NOT_SUPPORTED	The status of the Active_EP_store_rsp command.

2.4.4.1.16.1 When Generated

The Active_EP_store_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has space to store the discovery cache data for the Local Device), the request is not supported (meaning the Remote Device is not a Primary Discovery Cache device), or insufficient space exists.

2.4.4.1.16.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should re-perform discovery on the Primary Discovery Cache. If a NOT_PERMITTED status is returned, the local device must first issue a Discovery_store_req with a returned SUCCESS status. If an INSUFFICIENT_SPACE status is returned, the Local Device shall discontinue upload of discovery information, issue a Remove_node_cache_req (citing the Local Device), and cease attempts to upload discovery information to the Remote Device. If a SUCCESS status is returned, the Local Device should continue to upload its remaining discovery cache information to the Remote Device via the Simple_Desc_store_req.

2.4.4.1.17 Simple_Desc_store_rsp

The Simple_Desc_store_rsp command (ClusterID=0x801a) shall be formatted as illustrated in Figure 2.78.

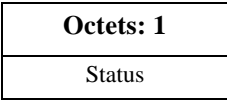


Figure 2.78 Format of the Simple_Desc_store_rsp Command Frame

Table 2.106 specifies the fields of the Simple_Desc_store_rsp command frame.

Table 2.106 Fields of the Simple_Desc_store_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INSUFFICIENT_SPACE, NOT_PERMITTED or NOT_SUPPORTED	The status of the Simple_desc_store_rsp command.

2.4.4.1.17.1 When Generated

The Simple_Desc_store_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has space to store the discovery cache data for the Local Device), the request is not supported (meaning the Remote Device is not a Primary Discovery Cache device), or insufficient space exists.

2.4.4.1.17.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should re-perform discovery on the Primary Discovery Cache. If a NOT_PERMITTED status is returned, the local device must first issue a Discovery_store_req with a returned SUCCESS status. If an INSUFFICIENT_SPACE status is returned, the Local Device shall discontinue upload of discovery information, issue a Remove_node_cache_req (citing the Local Device), and cease attempts to upload discovery information to the Remote Device. If a SUCCESS status is returned, the Local Device should continue to upload its remaining discovery cache information to the Remote Device via the Simple_Desc_store_req for other endpoints on the Local Device.

2.4.4.1.18 Remove_node_cache_rsp

The Remove_node_cache_rsp command (ClusterID=0x801b) shall be formatted as illustrated in Figure 2.79.

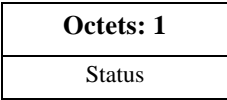


Figure 2.79 Format of the Remove_node_cache_rsp Command Frame

Table 2.107 specifies the fields of the Remove_node_cache_rsp command frame.

Table 2.107 Fields of the Remove_node_cache_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND or NOT_SUPPORTED	The status of the Remove_node_cache_rsp command

2.4.4.1.18.1 When Generated

The Remove_node_cache_rsp is provided to notify a Local Device of the request status from a Primary Discovery Cache device. Included in the response is a status code to notify the Local Device whether the request is successful (the Primary Cache Device has removed the discovery cache data for the indicated device of interest), or the request is not supported (meaning the Remote Device is not a Primary Discovery Cache device).

2.4.4.1.18.2 Effect on Receipt

Upon receipt, the Local Device shall determine whether the response status indicates that the Remote Device is not a Primary Cache Device as indicated by a NOT_SUPPORTED status. If a NOT_SUPPORTED status is returned, the Local Device should re-perform Find_node_cache_req to locate the Primary Discovery Cache device holding the discovery cache information for the indicated device of interest. When the Primary Discovery Cache device holding the discovery information for the device of interest is located, the Local Device should repeat the Remove_node_cache_req to successfully remove the discovery information. If a status of DEVICE_NOT_FOUND is received, this indicates that the Remote Device is the Primary Discovery Cache but does not hold the discovery information for the NWKAddr and the IEEEAddr presented in the request. The Local Device should employ the device discovery commands NWK_Addr_req and IEEE_Addr_req to determine the correct values for NWKAddr and IEEEAddr. If a SUCCESS status is returned, the Local Device has successfully removed the discovery cache information for the indicated device of interest within the request.

2.4.4.1.19 Find_node_cache_rsp

The Find_node_cache_rsp command (ClusterID=0x801c) shall be formatted as illustrated in Figure 2.80.

Octets: 2	2	8
CacheNWKAddr	NWKAddr	IEEEAddr

Figure 2.80 Format of the Find_node_cache_rsp Command Frame

Table 2.108 specifies the fields of the Find_node_cache_rsp command frame.

Table 2.108 Fields of the Find_node_cache_rsp Command

Name	Type	Valid Range	Description
CacheNWKAddr	Device Address	16-bit NWK Address	NWK Address for the Primary Discovery Cache device holding the discovery information (or the device of interest if it responded to the request directly).
NWKAddr	Device Address	16-bit NWK Address	NWK Address for the device of interest.
IEEEAddr	Device Address	64-bit IEEE Address	IEEE address for the device of interest.

2.4.4.1.19.1 When Generated

The Find_node_cache_rsp is provided to notify a Local Device of the successful discovery of the Primary Discovery Cache device for the given NWKAddr and IEEEAddr fields supplied in the request, or to signify that the device of interest is capable of responding to discovery requests. The Find_node_cache_rsp shall be generated only by Primary Discovery Cache devices holding discovery information for the NWKAddr and IEEEAddr in the request or the device of interest itself and all other Remote Devices shall not supply a response.

2.4.4.1.19.2 Effect on Receipt

Upon receipt, the Local Device shall utilize the CacheNWKAddr as the Remote Device address for subsequent discovery requests relative to the NWKAddr and IEEEAddr in the response.

2.4.4.1.20 Extended_Simple_Desc_rsp

The Extended_Simple_Desc_rsp command (ClusterID=0x801d) shall be formatted as illustrated in Figure 2.81.

Octet:1	2	1	1	1	1	Variable
Status	NWKAddrOfInterest	Endpoint	AppInputClusterCount	AppOutputClusterCount	StartIndex	AppClusterList

Figure 2.81 Format of the Extended_Simple_Desc_rsp Command Frame

Table 2.109 specifies the fields of the Extended_Simple_Desc_rsp command frame.

Table 2.109 Fields of the Extended_Simple_Desc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INVALID_EP, NOT_ACTIVE, DEVICE_NOT_FOUND, INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Extended_Simple_Desc_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.
Endpoint	8 bits	1-254	The endpoint on the destination.
AppInputClusterCount	8 bits	0x00-0xff	The total count of application input clusters in the Simple Descriptor for this endpoint.

Table 2.109 Fields of the Extended_Simple_Desc_rsp Command (Continued)

AppOutputClusterCount	8 bits	0x00-0xff	The total count of application output clusters in the Simple Descriptor for this endpoint.
StartIndex	8 bits	0x00-0xff	Starting index within the AppClusterList of the response represented by an ordered list of the Application Input Cluster List and Application Output Cluster List from the Simple Descriptor for this endpoint.
AppClusterList			A concatenated, ordered list of the AppInputClusterList and AppOutputClusterList, beginning with StartIndex, from the Simple Descriptor. This field shall only be included in the frame if the status field is equal to SUCCESS.

2.4.4.1.20.1 When Generated

The Extended_Simple_Desc_rsp is generated by a remote device in response to an Extended_Simple_Desc_req directed to the remote device. This command shall be unicast to the originator of the Extended_Simple_Desc_req command.

The remote device shall generate the Extended_Simple_Desc_rsp command using the format illustrated in Table 2.109. The NWKAddrOfInterest field shall match that specified in the original Extended_Simple_Desc_req command. If the endpoint field specified in the original Extended_Simple_Desc_req command does not fall within the correct range specified in Table 2.49, the remote device shall set the Status field to INVALID_EP, set the Endpoint and StartIndex fields to their respective values supplied in the request, and not include the AppClusterList field.

If the NWKAddrOfInterest field matches the network address of the remote device, it shall determine whether the endpoint field specifies the identifier of an active endpoint on the device. If the endpoint field corresponds to an active endpoint, the remote device shall set the Status field to SUCCESS, set the AppClusterList field to the sequence of octets from the concatenated AppInputClusterList and AppOutputClusterList from the Simple Descriptor (Tables 2.39), and supply that field as AppClusterList in the response. Note that dependent on the value of StartIndex in the request, the results in AppClusterList may be empty (for example, the StartIndex begins after the sequence of octets given by the concatenation of AppInputClusterList and AppOutputClusterList). If the endpoint

field does not correspond to an active endpoint, the remote device shall set the Status field to NOT_ACTIVE, set the StartIndex field to the value supplied in the request, and not include the AppClusterList field.

2.4.4.1.20.2 Effect on Receipt

On receipt of the Extended_Simple_Desc_rsp command, the recipient is either notified of the requested AppClusterList on the endpoint of the remote device indicated in the original Extended_Simple_Desc_req command or notified of an error. If the Extended_Simple_Desc_rsp command is received with a Status of SUCCESS, the AppClusterList field shall contain the requested portion of the application input cluster list and application output cluster list, starting with the StartIndex. Otherwise, the Status field indicates the error and the AppClusterList field shall not be included.

2.4.4.1.21 Extended_Active_EP_rsp

The Extended_Active_EP_rsp command (ClusterID=0x801e) shall be formatted as illustrated in Figure 2.82.

Octet: 1	2	1	1	Variable
Status	NWKAddrOfInterest	ActiveEPCount	StartIndex	ActiveEPList

Figure 2.82 Format of the Extended_Active_EP_rsp Command Frame

Table 2.110 specifies the fields of the Extended_Active_EP_rsp command frame.

Table 2.110 Fields of the Extended_Active_EP_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, DEVICE_NOT_FOUND , INV_REQUESTTYPE or NO_DESCRIPTOR	The status of the Extended_Active_EP_req command.
NWKAddrOfInterest	Device Address	16-bit NWK address	NWK address for the request.

Table 2.110 Fields of the Extended_Active_EP_rsp Command

ActiveEPCount	Integer	0x00-0xff	The count of active endpoints on the Remote Device.
StartIndex	Integer	0x00-0xff	Starting index for the list of active endpoints for this report.
ActiveEPList			List of bytes each of which represents an 8-bit endpoint. The list begins with the entry starting with StartIndex and continues until the remaining active endpoints are listed or the ASDU size is exhausted with whole endpoint entries.

2.4.4.1.21.1 When Generated

The Extended_Active_EP_rsp is generated by a remote device in response to an Extended_Active_EP_req directed to the remote device. This command shall be unicast to the originator of the Extended_Active_EP_req command.

The remote device shall generate the Extended_Active_EP_rsp command using the format illustrated in Table 2.110. The NWKAddrOfInterest field shall match that specified in the original Extended_Active_EP_req command. If the NWKAddrOfInterest field matches the network address of the remote device, it shall set the Status field to SUCCESS, set the ActiveEPCount field to the number of active endpoints on that device, and include an ascending list of all the identifiers of the active endpoints, beginning with StartIndex, on that device in the ActiveEPList field and continuing until the remaining list of active endpoints from StartIndex forward is listed or until the ASDU size is exhausted with whole endpoint entries.

If the NWKAddrOfInterest field does not match the network address of the remote device and it is an end device, it shall set the Status field to INV_REQUESTTYPE, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the NWKAddrOfInterest field does not match the network address of the remote device and it is the coordinator or a router, it shall determine whether the NWKAddrOfInterest field matches the network address of a device it holds in a discovery cache. If the NWKAddrOfInterest field does not match the network address of a device it holds in a discovery cache, it shall set the Status field to DEVICE_NOT_FOUND, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the NWKAddrOfInterest matches the network address of a device held in a discovery cache on the remote device, it shall determine whether that device has any active endpoints. If the discovery information corresponding to the ActiveEP request has not yet been uploaded to the discovery cache, the remote device shall set the Status field to NO_DESCRIPTOR, set the ActiveEPCount field to 0, and not include the

ActiveEPList field. If the cached device has no active endpoints, the remote device shall set the Status field to SUCCESS, set the ActiveEPCount field to 0, and not include the ActiveEPList field. If the cached device has active endpoints, the remote device shall set the Status field to SUCCESS, set the ActiveEPCount field to the number of active endpoints on that device and include an ascending list of all the identifiers of the active endpoints, beginning with StartIndex, on that device in the ActiveEPList field.

2.4.4.1.21.2 Effect on Receipt

On receipt of the Extended_Active_EP_rsp command, the recipient is either notified of the active endpoints of the remote device indicated in the original Extended_Active_EP_req command or notified of an error. If the Extended_Active_EP_rsp command is received with a Status of SUCCESS, the ActiveEPCount field indicates the number of entries in the ActiveEPList field. Otherwise, the Status field indicates the error and the ActiveEPList field shall not be included. The requesting device may need to employ Extended_Active_EP_req multiple times, with different StartIndex values, to receive the full ActiveEPList from the remote device.

2.4.4.2 End Device Bind, Bind, Unbind Bind Management Server Services

Table 2.111 lists the commands supported by Device Profile: End Device Bind, Bind and Unbind Server Services. Each of these primitives will be discussed in the following sub-clauses.

Table 2.111 End Device Bind, Unbind and Bind Management Server Services Primitives

End Device Bind, Bind and Unbind Server Service Commands	Server Processing
End_Device_Bind_rsp	O
Bind_rsp	O
Unbind_rsp	O
Bind_Register_rsp	O
Replace_Device_rsp	O
Store_Bkup_Bind_Entry_rsp	O
Remove_Bkup_Bind_Entry_rsp	O
Backup_Bind_Table_rsp	O

Table 2.111 End Device Bind, Unbind and Bind Management
Server Services Primitives (Continued)

Recover_Bind_Table_rsp	O
Backup_Source_Bind_rsp	O
Recover_Source_Bind_rsp	O

2.4.4.2.1 End_Device_Bind_rsp

The End_Device_Bind_rsp command (ClusterID=0x8020) shall be formatted as illustrated in Figure 2.83.

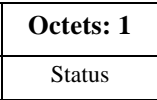


Figure 2.83 Format of the End_Device_Bind_rsp Command Frame

Table 2.112 specifies the fields of the End_Device_Bind_rsp command frame.

Table 2.112 Fields of the End_Device_Bind_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INVALID_EP, TIMEOUT, NO_MATCH, or DEVICE_BINDING_TABLE_FULL	The status of the End_Device_Bind_req command

2.4.4.2.1.1 When Generated

The End_Device_Bind_rsp is generated by the ZigBee Coordinator in response to an End_Device_Bind_req and contains the status of the request. This command shall be unicast to each device involved in the bind attempt, using the acknowledged data service.

A Status of NOT_SUPPORTED indicates that the request was directed to a device which was not the ZigBee Coordinator or that the ZigBee Coordinator does not support End Device Binding. Otherwise, End_Device_Bind_req processing is performed as described below, including transmission of the End_Device_Bind_rsp.

2.4.4.2.1.2 Effect on Receipt

When an End_Device_Bind_req is received, determination is made if a Status of NOT_SUPPORTED is warranted as indicated in the previous section. Assuming

this device is the ZigBee Coordinator, the supplied endpoint shall be checked to determine whether it falls within the specified range. If it does not, a Status of INVALID_EP shall be returned. If the supplied endpoint falls within the specified range and if this is the first End_Device_Bind_req submitted for evaluation, it shall be stored and a timer started which expires at a pre-configured timeout value. This timeout value shall be a configurable item on the ZigBee Coordinator. If the timer expires before a second End_Device_Bind_req is received, a Status of TIMEOUT is returned. Otherwise, if a second End_Device_Bind_req is received within the timeout window, the two End_Device_Bind_req's are compared for a match. A Status of NO_MATCH indicates that two End_Device_Bind_req were evaluated for a match, but either the ProfileID parameters did not match or the ProfileID parameter matched but there was no match of any element of the InClusterList or OutClusterList. A Status of SUCCESS means that a match was detected and a resulting Bind_req will subsequently be directed to the device indicated by the BindingTarget field of the End_Device_Bind_req with matched elements of the OutClusterList.

2.4.4.2.2 Bind_rsp

The Bind_rsp command (ClusterID=0x8021) shall be formatted as illustrated in Figure 2.84.

Octets: 1
Status

Figure 2.84 Format of the Bind_rsp Command Frame

Table 2.113 specifies the fields of the Bind_rsp command frame.

Table 2.113 Fields of the Bind_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INVALID_EP, TABLE_FULL or NOT_AUTHORIZED	The status of the Bind_req command.

2.4.4.2.2.1 When Generated

The Bind_rsp is generated in response to a Bind_req. If the Bind_req is processed and the Binding Table entry committed on the Remote Device, a Status of SUCCESS is returned. If the Remote Device is not a Primary binding table cache or the SrcAddress, a Status of NOT_SUPPORTED is returned. The supplied endpoint shall be checked to determine whether it falls within the specified range. If it does not, a Status of INVALID_EP shall be returned. If the Remote Device is

the Primary binding table cache or SrcAddress but does not have Binding Table resources for the request, a Status of TABLE_FULL is returned.

2.4.4.2.2 Effect on Receipt

Upon receipt, error checking is performed on the request as described in the previous section. Assuming the Status is SUCCESS, the parameters from the Bind_req are entered into the Binding Table at the Remote Device via the APSME-BIND.request primitive.

2.4.4.2.3 Unbind_rsp

The Unbind_rsp command (ClusterID=0x8022) shall be formatted as illustrated in Figure 2.85.

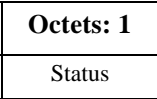


Figure 2.85 Format of the Unbind_rsp Command Frame

Table 2.114 specifies the fields of the Unbind_rsp command frame.

Table 2.114 Fields of the Unbind_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INVALID_EP, NO_ENTRY or NOT_AUTHORIZED	The status of the Unbind_req command.

2.4.4.2.3.1 When Generated

The Unbind_rsp is generated in response to an Unbind_req. If the Unbind_req is processed and the corresponding Binding Table entry is removed from the Remote Device, a Status of SUCCESS is returned. If the Remote Device is not the ZigBee Coordinator or the SrcAddress, a Status of NOT_SUPPORTED is returned. The supplied endpoint shall be checked to determine whether it falls within the specified range. If it does not, a Status of INVALID_EP shall be returned. If the Remote Device is the ZigBee Coordinator or SrcAddress but does not have a Binding Table entry corresponding to the parameters received in the request, a Status of NO_ENTRY is returned.

2.4.4.2.3.2 Effect on Receipt

Upon receipt, error checking is performed on the response. If the status is SUCCESS, the device has successfully removed the binding entry for the parameters specified in the Unbind_req.

2.4.4.2.4 Bind_Register_rsp

The Bind_Register_rsp command (ClusterID=0x8023) shall be formatted as illustrated in Figure 2.86.

Octets: 1	2	2	Variable
Status	BindingTableEntries	BindingTableListCount	BindingTableList

Figure 2.86 Format of the Bind_Register_rsp Command Frame

Table 2.115 specifies the fields of the Bind_Register_rsp command frame.

Table 2.115 Fields of the Bind_Register_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, TABLE_FULL	The status of the Bind_Register_reg command.
BindingTableEntries	Integer	0x0000 - 0ffff	Number of binding table entries for the requesting device held by the primary binding table cache.
BindingTableListCount	Integer	0x0000 - 0xffff	Number of source binding table entries contained in this response.
BindingTableList	List of source binding descriptors	This list shall contain the number of elements given by the BindingTableListCount	A list of source binding.

2.4.4.2.4.1 When Generated

The Bind_Register_rsp is generated from a primary binding table cache device in response to a Bind_Register_req and contains the status of the request. This command shall be unicast to the requesting device.

If the device receiving the Bind_Register_req is not a primary binding table cache a Status of NOT_SUPPORTED is returned. If its list of devices which choose to store their own binding table entries is full, a status of TABLE_FULL is returned. In these error cases, BindingTableEntries and BindingTableListCount shall be zero and BindingTableList shall be empty. A Status of SUCCESS indicates that the requesting device has been successfully registered.

In the successful case, the primary binding table cache device shall search its cache for existing entries whose source address is the same as the parameter supplied in the Bind_Register_req command. The number of such entries is given in the response as BindingTableEntries. The entries are used to generate BindingTableList up to the maximum that can be contained in the response. The actual number of entries is given in the response as BindingTableListCount and

may be less than BindingTableEntries if this is too large. In this case (which is expected to be rare) the primary binding table cache device shall use Bind_req commands to send the rest of the entries to the requesting device.

2.4.4.2.4.2 Effect on Receipt

The requesting device is notified of the results of its attempt to register. If successful, it shall store the source binding table entries from the response into its source binding table.

2.4.4.2.5 Replace_Device_rsp

The Replace_Device_rsp command (ClusterID=0x8024) shall be formatted as illustrated in Figure 2.87.

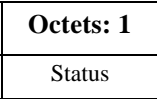


Figure 2.87 Format of the Replace_Device_rsp Command Frame

Table 2.116 specifies the fields of the Replace_Device_rsp command frame

Table 2.116 Fields of the Replace_Device_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED, INV_REQUESTTYPE	The status of the Replace_Device_req command.

2.4.4.2.5.1 When Generated

The Replace_Device_rsp is generated from a primary binding table cache device in response to a Replace_Device_req and contains the status of the request. This command shall be unicast to the requesting device. If the device receiving the Replace_Device_req is not a primary binding table cache, a Status of NOT_SUPPORTED is returned. The primary binding table cache shall search its binding table for entries whose source address and source endpoint, or whose destination address and destination endpoint match OldAddress and OldEndpoint, as described in the text for Replace_Device_req. It shall change these entries to have NewAddress and possibly NewEndpoint. It shall then return a response of SUCCESS.

2.4.4.2.5.2 Effect on Receipt

The requesting device is notified of the status of its Replace_Device_req command.

2.4.4.2.6 Store_Bkup_Bind_Entry_rsp

The Store_Bkup_Bind_Entry_rsp command (ClusterID=0x8025) shall be formatted as illustrated in Figure 2.88.

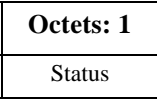


Figure 2.88 Format of the Store_Bkup_Bind_Entry_rsp Command Frame

Table 2.117 specifies the fields of the Store_Bkup_Bind_Entry_rsp command frame.

Table 2.117 Fields of the Store_Bkup_Bind_Entry_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INV_REQUESTTYPE. TABLE_FULL	The status of the Store_Bkup_Bind_Entry_rsp command.

2.4.4.2.6.1 When Generated

The Store_Bkup_Bind_Entry_rsp is generated from a backup binding table cache device in response to a Store_Bkup_Bind_Entry_req from a primary binding table cache, and contains the status of the request. This command shall be unicast to the requesting device. If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall add the binding entry to its binding table and return a status of SUCCESS. If there is no room, it shall return a status of TABLE_FULL.

2.4.4.2.6.2 Effect on Receipt

The requesting device is notified of the status of its attempt to store a bind entry.

2.4.4.2.7 Remove_Bkup_Bind_Entry_rsp

The Remove_Bkup_Bind_Entry_rsp command (ClusterID=0x8026) shall be formatted as illustrated in Figure 2.89.

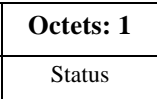


Figure 2.89 Format of the Remove_Bkup_Bind_Entry_rsp Command Frame

Table 2.118 specifies the fields of the Remove_Bkup_Bind_Entry_rsp command frame.

Table 2.118 Fields of the Remove_Bkup_Bind_Entry_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INV_REQUESTTYPE, NO_ENTRY	The status of the Remove_Bkup_Bind_Entry_rsp command.

2.4.4.2.7.1 When Generated

The Remove_Bkup_Bind_Entry_rsp is generated from a backup binding table cache device in response to a Remove_Bkup_Bind_Entry_req from the primary binding table cache and contains the status of the request. This command shall be unicast to the requesting device. If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall delete the binding entry from its binding table and return a status of SUCCESS. If the entry is not found, it shall return a status of NO_ENTRY.

2.4.4.2.7.2 Effect on Receipt

The requesting device is notified of the status of its attempt to remove a bind entry from the backup cache.

2.4.4.2.8 Backup_Bind_Table_rsp

The Backup_Bind_Table_rsp command (ClusterID=0x8027) shall be formatted as illustrated in Figure 2.90.

Octets: 1	2
Status	EntryCount

Figure 2.90 Format of the Backup_Bind_Table_rsp Command Frame

Table 2.119 specifies the fields of the Backup_Bind_Table_rsp command frame.

Table 2.119 Fields of the Backup_Bind_Table_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, TABLE_FULL, INV_REQUESTTYPE	The status of the Backup_Bind_Table_rsp command.
EntryCount	Integer	0x0000 - 0xFFFF	The number of entries in the backup binding table.

2.4.4.2.8.1 When Generated

The Backup_Bind_Table_rsp is generated from a backup binding table cache device in response to a Backup_Bind_Table_req from a primary binding table cache and contains the status of the request. This command shall be unicast to the requesting device. If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall overwrite the binding entries in its binding table starting with StartIndex and continuing for BindingTableListCount entries. If this exceeds its table size, it shall fill in as many entries as possible and return a status of TABLE_FULL and the EntryCount parameter will be the number of entries in the table. Otherwise, it shall return a status of SUCCESS and EntryCount will be equal to StartIndex + BindingTableListCount from Backup_Bind_Table_req.

2.4.4.2.8.2 Effect on Receipt

The requesting device is notified of the status of its attempt to store a binding table.

2.4.4.2.9 Recover_Bind_Table_rsp

The Backup_Bind_Table_rsp command (ClusterID=0x8028) shall be formatted as illustrated in Figure 2.91.

Octets: 1	2	2	2	Variable
Status	BindingTableEntries	StartIndex	BindingTableListCount	BindingTableList

Figure 2.91 Format of the Backup_Bind_Table_rsp Command Frame

Table 2.120 specifies the fields of the Recover_Bind_Table_rsp command frame.

Table 2.120 Fields of the Recover_Bind_Table_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, INV_REQUESTTYPE, NO_ENTRY	The status of the Recover_Bind_Table_rsp command.
BindingTable Entries	Integer	0x0000 - 0xffff	Total number of binding table entries in the backup binding cache.
StartIndex	Integer	0x0000 - 0xffff	Starting index within the binding table to begin reporting for the binding table list.
BindingTable ListCount	Integer	0x0000 - 0xffff	Number of binding entries included within BindingTableList.
BindingTable List	Integer	The list shall contain the number of elements given by BindingTableListCount	A list of descriptors, beginning with the StartIndex element and continuing for BindingTableListCount of elements in the backup binding table cache.

2.4.4.2.9.1 When Generated

The Recover_Bind_Table_rsp is generated from a backup binding table cache device in response to a Recover_Bind_Table_req from a primary binding table cache and contains the status of the request. This command shall be unicast to the requesting device. If the responding device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall prepare a list of binding table entries from its backup beginning with StartIndex. It will fit in as many entries as possible into a Recover_Bind_Table_rsp command and return a status of SUCCESS. If StartIndex is more than the number of entries in the Binding table, a status of NO_ENTRY is returned. For a successful response, BindingTableEntries is the total number of entries in the backup binding table, and BindingTableListCount is the number of entries which is being returned in the response.

2.4.4.2.9.2 Effect on Receipt

The requesting device is notified of the status of its attempt to restore a binding table.

2.4.4.2.10 Backup_Source_Bind_rsp

The Backup_Source_Bind_rsp command (ClusterID=0x8029) shall be formatted as illustrated in Figure 2.92.

Octets: 1
Status

Figure 2.92 Format of the Backup_Source_Bind_rsp Command Frame

Table 2.121 specifies the fields of the Backup_Source_Bind_rsp command frame.

Table 2.121 Fields of the Backup_Source_Bind_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, TABLE_FULL, INV_REQUESTTYPE	The status of the Backup_Source_Bind_rsp command.

2.4.4.2.10.1 When Generated

The Backup_Source_Bind_rsp is generated from a backup binding table cache device in response to a Backup_Source_Bind_req from a primary binding table cache and contains the status of the request. This command shall be unicast to the requesting device. If the remote device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall overwrite its backup source binding table starting with StartIndex and continuing for BindingTableListCount entries. If this exceeds its table size, it shall return a status of TABLE_FULL. Otherwise it shall return a status of SUCCESS.

2.4.4.2.10.2 Effect on Receipt

The requesting device is notified of the status of its attempt to backup the source binding table.

2.4.4.2.11 Recover_Source_Bind_rsp

The Recover_Source_Bind_rsp command (ClusterID=0x802a) shall be formatted as illustrated in Figure 2.93.

Octets: 1	2	2	2	Variable
Status	SourceTableEntries	StartIndex	SourceTableListCount	SourceTableList

Figure 2.93 Format of the Recover_Source_Bind_rsp Command Frame

Table 2.122 specifies the fields of the Recover_Source_Bind_rsp command frame.

Table 2.122 Fields of the Recover_Source_Bind_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, NOT_SUPPORTED, TABLE_FULL, INV_REQUESTTYPE	The status of the Recover_Source_Bind_rsp command.
SourceTableEntries	Integer	0x0000 - 0xffff	Total number of source table entries in the backup binding cache.
StartIndex	Integer	0x0000 - 0xffff	Starting index within the source table to begin reporting for the source table list.
SourceTableListCount	Integer	0x0000 - 0xffff	Number of source table entries included within SourceTableList.
SourceTableList	List of source descriptors	The list shall contain the number of elements given by SourceTableListCount	A list of descriptors, beginning with the StartIndex element and continuing for SourceTableListCount of elements in the backup source table cache (consisting of IEEE addresses).

2.4.4.2.11.1 When Generated

The Recover_Source_Bind_rsp is generated from a backup binding table cache device in response to a Recover_Source_Bind_req from a primary binding table cache and contains the status of the request. This command shall be unicast to the requesting device. If the responding device is not a backup binding table cache, it shall return a status of NOT_SUPPORTED. If the originator of the request is not recognized as a primary binding table cache, it shall return a status of INV_REQUESTTYPE. Otherwise, the backup binding table cache shall prepare a list of binding table entries from its backup beginning with StartIndex. It will fit in as many entries as possible into a Recover_Source_Bind_rsp command and return a status of SUCCESS. If StartIndex is more than the number of entries in the Source table, a status of NO_ENTRY is returned. For a successful response, SourceTableEntries is the total number of entries in the backup source table, and SourceTableListCount is the number of entries which is being returned in the response.

2.4.4.2.11.2 Effect on Receipt

The requesting device is notified of the status of its attempt to restore a source binding table.

2.4.4.3 Network Management Server Services

Table 2.123 lists the commands supported by Device Profile: Network Management Server Services. Each of these commands will be discussed in the following sub-clauses.

Table 2.123 Network Management Server Service Commands

Network Management Server Service Command	Server Processing
Mgmt_NWK_Disc_rsp	O
Mgmt_Lqi_rsp	O
Mgmt_Rtg_rsp	O
Mgmt_Bind_rsp	O
Mgmt_Leave_rsp	O
Mgmt_Direct_Join_rsp	O
Mgmt_Permit_Joining_rsp	M
Mgmt_Cache_rsp	O
Mgmt_NWK_Update_notify	O

2.4.4.3.1 Mgmt_NWK_Disc_rsp

The Mgmt_NWK_Disc_rsp command (ClusterID=0x8030) shall be formatted as illustrated in Figure 2.94.

Octets: 1	1	1	1	Variable
Status	Network Count	Start Index	NetworkList Count	NetworkList

Figure 2.94 Format of the Mgmt_NWK_Disc_rsp Command Frame

Table 2.124 specifies the fields of the Mgmt_NWK_Disc_rsp command frame.

Table 2.124 Fields of the Mgmt_NWK_Disc_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED or any status code returned from the NLME-NETWORK-DISCOVERY.request primitive.	The status of the Mgmt_NWK_Disc_req command.

Table 2.124 Fields of the Mgmt_NWK_Disc_rsp Command (Continued)

Name	Type	Valid Range	Description
NetworkCount	Integer	0x00-0xff	The total number of networks reported by the NLME-NETWORK-DISCOVERY.confirm.
StartIndex	Integer	0x00-0xff	The starting point in the NetworkList from the NLME-NETWORK-DISCOVERY.confirm where reporting begins for this response.
NetworkListCount	Integer	0x00-0xff	The number of network list descriptors reported within this response.
NetworkList	List of Network Descriptors	The list shall contain the number of elements given by the NetworkListCount parameter.	A list of descriptors, one for each of the networks discovered, beginning with the StartIndex element and continuing for NetworkListCount, of the elements returned by the NLME-NETWORK-DISCOVERY.confirm primitive. Each entry shall be formatted as illustrated in table Table 2.125.

Table 2.125 NetworkList Record Format

Name	Size (Bits)	Valid Range	Description
ExtendedPanID	64	A 64-bit PAN identifier	The 64-bit extended PAN identifier of the discovered network.
LogicalChannel	8	Selected from the available logical channels supported by the PHY (see [B1])	The current logical channel occupied by the network.
StackProfile	4	0x0-0xf	A ZigBee stack profile identifier indicating the stack profile in use in the discovered network.
ZigBeeVersion	4	0x0-0xf	The version of the ZigBee protocol in use in the discovered network.
BeaconOrder	4	0x0-0xf	This specifies how often the MAC sub-layer beacon is to be transmitted by a given device on the network. For a discussion of MAC sub-layer beacon order see [B1].

Table 2.125 NetworkList Record Format

Name	Size (Bits)	Valid Range	Description
SuperframeOrder	4	0x0-0xf	For beacon-oriented networks, <i>i.e.</i> , beacon order < 15, this specifies the length of the active period of the superframe. For a discussion of MAC sub-layer superframe order see [B1].
PermitJoining	1	TRUE or FALSE	A value of TRUE indicates that at least one ZigBee router on the network currently permits joining, <i>i.e.</i> , its NWK has been issued an NLME-PERMIT-JOINING primitive and the time limit, if given, has not yet expired.
Reserved	7		Each of these bits shall be set to 0.

2.4.4.3.1.1 When Generated

The Mgmt_NWK_Disc_rsp is generated in response to an Mgmt_NWK_Disc_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned and all parameter fields after the Status field shall be omitted. Otherwise, the Remote Device shall implement the following process.

Upon receipt of and after support for the Mgmt_NWK_Disc_req has been verified, the Remote Device shall issue an NLME-NETWORK-DISCOVERY.request primitive using the ScanChannels and ScanDuration parameters, supplied in the Mgmt_NWK_Disc_req command. Upon receipt of the NLME-NETWORK-DISCOVERY.confirm primitive, the Remote Device shall report the results, starting with the StartIndex element, via the Mgmt_NWK_Disc_rsp command. The NetworkList field shall contain whole NetworkList records, formatted as specified in Table 2.125, until the limit on MSDU size, *i.e.*, *aMaxMACFrameSize* (see [B1]), is reached. The number of results reported shall be set in the NetworkListCount.

2.4.4.3.1.2 Effect on Receipt

The local device is notified of the results of its attempt to perform a remote network discovery.

2.4.4.3.2 Mgmt_Lqi_rsp

The Mgmt_Lqi_rsp command (ClusterID=0x8031) shall be formatted as illustrated in Figure 2.95.

Octets: 1	1	1	1	Variable
Status	NeighborTable Entries	Start Index	NeighborTable ListCount	NeighborTable List

Figure 2.95 Format of the Mgmt_Lqi_rsp Command Frame

Table 2.126 specifies the fields of the Mgmt_Lqi_rsp command frame.

Table 2.126 Fields of the Mgmt_Lqi_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED or any status code returned from the NLME-GET.confirm primitive	The status of the Mgmt_Lqi_req command.
NeighborTableEntries	Integer	0x00-0xff	Total number of Neighbor Table entries within the Remote Device.
StartIndex	Integer	0x00-0xff	Starting index within the Neighbor Table to begin reporting for the NeighborTableList.
NeighborTableListCount	Integer	0x00-0x02	Number of Neighbor Table entries included within NeighborTableList.
NeighborTableList	List of Neighbor Descriptors	The list shall contain the number elements given by the NeighborTableListCount	A list of descriptors, beginning with the StartIndex element and continuing for NeighborTableListCount, of the elements in the Remote Device's Neighbor Table including the device address and associated LQI (see Table 2.127 for details).

Table 2.127 NeighborTableList Record Format

Name	Size (Bits)	Valid Range	Description
Extended PAN Id	64	A 64-bit PAN identifier	The 64-bit extended PAN identifier of the neighboring device.
Extended address	64	An extended 64-bit, IEEE address	64-bit IEEE address that is unique to every device. If this value is unknown at the time of the request, this field shall be set to 0xffffffffffffff.
Network address	16	Network address	The 16-bit network address of the neighboring device.
Device type	2	0x0-0x3	The type of the neighbor device: 0x0 = ZigBee coordinator 0x1 = ZigBee router 0x2 = ZigBee end device 0x3 = Unknown
RxOnWhenIdle	2	0x0-0x2	Indicates if neighbor's receiver is enabled during idle portions of the CAP: 0x0 = Receiver is off 0x1 = Receiver is on 0x2 = unknown
Relationship	3	0x0-0x4	The relationship between the neighbor and the current device: 0x0 = neighbor is the parent 0x1 = neighbor is a child 0x2 = neighbor is a sibling 0x3 = None of the above 0x4 = previous child
Reserved	1		This reserved bit shall be set to 0.
Permit joining	2	0x0-0x2	An indication of whether the neighbor device is accepting join requests: 0x0 = neighbor is not accepting join requests 0x1 = neighbor is accepting join requests 0x2 = unknown

Table 2.127 NeighborTableList Record Format (Continued)

Name	Size (Bits)	Valid Range	Description
Reserved	6		Each of these reserved bits shall be set to 0.
Depth	8	0x00- <i>nwkMaxDepth</i>	The tree depth of the neighbor device. A value of 0x00 indicates that the device is the ZigBee coordinator for the network.
LQI	8	0x00-0xff	The estimated link quality for RF transmissions from this device. See [B1] for discussion of how this is calculated.

2.4.4.3.2.1 When Generated

The Mgmt_Lqi_rsp is generated in response to an Mgmt_Lqi_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned and all parameter fields after the Status field shall be omitted. Otherwise, the Remote Device shall implement the following processing.

Upon receipt of and after support for the Mgmt_Lqi_req has been verified, the Remote Device shall perform an NLME-GET.request (for the *nwkNeighborTable* attribute) and process the resulting neighbor table (obtained via the NLME-GET.confirm primitive) to create the Mgmt_Lqi_rsp command. If *nwkNeighborTable* was successfully obtained but one or more of the fields required in the NeighborTableList record (see Table 2.127) are not supported (as they are optional), the Mgmt_Lqi_rsp shall return a status of NOT_SUPPORTED and all parameter fields after the Status field shall be omitted. Otherwise, the Mgmt_Lqi_rsp command shall contain the same status that was contained in the NLME-GET.confirm primitive and if this was not SUCCESS, all parameter fields after the status field shall be omitted.

From the *nwkNeighborTable* attribute, the neighbor table shall be accessed, starting with the index specified by StartIndex, and shall be moved to the NeighborTableList field of the Mgmt_Lqi_rsp command. The entries reported from the neighbor table shall be those, starting with StartIndex and including whole NeighborTableList records (see Table 2.127) until the limit on MSDU size, i.e., *aMaxMACFrameSize* (see [B1]), is reached. Within the Mgmt_Lqi_Rsp command, the NeighborTableEntries field shall represent the total number of Neighbor Table entries in the Remote Device. The parameter NeighborTableListCount shall be the number of entries reported in the NeighborTableList field of the Mgmt_Lqi_rsp command.

The extended address, device type, RxOnWhenIdle, and permit joining fields have “unknown” values which shall be returned where the values are not available.

2.4.4.3.2.2 Effect on Receipt

The local device is notified of the results of its attempt to obtain the neighbor table.

2.4.4.3.3 Mgmt_Rtg_rsp

The Mgmt_Rtg_rsp command (ClusterID=0x8032) shall be formatted as illustrated in Figure 2.96.

Octets: 1	1	1	1	Variable
Status	RoutingTable Entries	Start Index	RoutingTable ListCount	RoutingTable List

Figure 2.96 Format of the Mgmt_Rtg_rsp Command Frame

Table 2.128 specifies the fields of the Mgmt_Rtg_rsp command frame.

Table 2.128 Fields of the Mgmt_Rtg_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED or any status code returned from the NLME-GET.confirm primitive	The status of the Mgmt_Rtg_req command.
RoutingTableEntries	Integer	0x00-0xff	Total number of Routing Table entries within the Remote Device.
StartIndex	Integer	0x00-0xff	Starting index within the Routing Table to begin reporting for the RoutingTableList.
RoutingTableListCount	Integer	0x00-0xff	Number of Routing Table entries included within RoutingTableList.
RoutingTableList	List of Routing Descriptors	The list shall contain the number elements given by the RoutingTableListCount	A list of descriptors, beginning with the StartIndex element and continuing for RoutingTableListCount, of the elements in the Remote Device's Routing Table (see the Table 2.129 for details).

Table 2.129 RoutingTableList Record Format

Name	Size (Bits)	Valid Range	Description
Destination address	16	The 16-bit network address of this route.	Destination address.
Status	3	The status of the route.	0x0=ACTIVE. 0x1=DISCOVERY_UNDERWAY. 0x2=DISCOVERY_FAILED. 0x3=INACTIVE. 0x4=VALIDATION_UNDERWAY 0x5-0x7=RESERVED.
Memory Constrained	1		A flag indicating whether the device is a memory constrained concentrator.
Many-to-one	1		A flag indicating that the destination is a concentrator that issued a many-to-one request.
Route record required	1		A flag indicating that a route record command frame should be sent to the destination prior to the next data packet.
Reserved	2		
Next-hop address	16	The 16-bit network address of the next hop on the way to the destination.	Next-hop address.

2.4.4.3.3.1 When Generated

The Mgmt_Rtg_rsp is generated in response to an Mgmt_Rtg_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned and all parameter fields after the Status field shall be omitted. Otherwise, the Remote Device shall implement the following processing.

Upon receipt of and after support for the Mgmt_Rtg_req has been verified, the Remote Device shall perform an NLME-GET.request (for the *nwkRouteTable* attribute) and process the resulting NLME-GET.confirm (containing the *nwkRouteTable* attribute) to create the Mgmt_Rtg_rsp command. The Mgmt_Rtg_rsp command shall contain the same status that was contained in the NLME-GET.confirm primitive and if this was not SUCCESS, all parameter fields after the status field shall be omitted.

From the *nwkRouteTable* attribute, the routing table shall be accessed, starting with the index specified by *StartIndex*, and moved to the *RoutingTableList* field of the *Mgmt_Rtg_rsp* command. The entries reported from the routing table shall be those, starting with *StartIndex* and including whole *RoutingTableList* records (see Table 2.128) until MSDU size limit, *i.e.*, *aMaxMACFrameSize* (see [B1]), is reached. Within the *Mgmt_Rtg_Rsp* command, the *RoutingTableEntries* field shall represent the total number of Routing Table entries in the Remote Device. The *RoutingTableListCount* field shall be the number of entries reported in the *RoutingTableList* field of the *Mgmt_Rtg_req* command.

2.4.4.3.3.2 Effect on Receipt

The local device is notified of the results of its attempt to obtain the routing table.

2.4.4.3.4 Mgmt_Bind_rsp

The *Mgmt_Bind_rsp* command (*ClusterID*=0x8033) shall be formatted as illustrated in Figure 2.97.

Octets: 1	1	1	1	Variable
Status	BindingTable Entries	Start Index	BindingTable ListCount	BindingTable List

Figure 2.97 Format of the *Mgmt_Bind_rsp* Command Frame

Table 2.130 specifies the fields of the *Mgmt_Bind_rsp* command frame.

Table 2.130 Fields of the *Mgmt_Bind_rsp* Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED or any status code returned from the APSME-GET.confirm primitive	The status of the <i>Mgmt_Bind_req</i> command.
BindingTableEntries	Integer	0x00-0xff	Total number of Binding Table entries within the Remote Device.

Table 2.130 Fields of the Mgmt_Bind_rsp Command (Continued)

Name	Type	Valid Range	Description
StartIndex	Integer	0x00-0xff	Starting index within the Binding Table to begin reporting for the BindingTableList.
BindingTableListCount	Integer	0x00-0xff	Number of Binding Table entries included within BindingTableList.
BindingTableList	List of Binding Descriptors	The list shall contain the number elements given by the BindingTableListCount	A list of descriptors, beginning with the StartIndex element and continuing for BindingTableListCount, of the elements in the Remote Device's Binding Table (see Table 2.131 for details).

Table 2.131 BindingTableList Record Format

Name	Size (Bits)	Valid Range	Description
SrcAddr	64	A valid 64-bit IEEE address	The source IEEE address for the binding entry.
SrcEndpoint	8	0x01 - 0xfe	The source endpoint for the binding entry.
ClusterId	16	0x0000 - 0xffff	The identifier of the cluster on the source device that is bound to the destination device.

Table 2.131 BindingTableList Record Format (Continued)

Name	Size (Bits)	Valid Range	Description
DstAddrMode	8	0x00 - 0xff	The addressing mode for the destination address. This field can take one of the non-reserved values from the following list: 0x00 = reserved 0x01 = 16-bit group address for DstAddr and DstEndpoint not present 0x02 = reserved 0x03 = 64-bit extended address for DstAddr and DstEndp present 0x04 – 0xff = reserved
DstAddr	16/64	As specified by the DstAddrMode field	The destination address for the binding entry.
DstEndpoint	0/8	0x01 - 0xff	This field shall be present only if the DstAddrMode field has a value of 0x03 and, if present, shall be the destination endpoint for the binding entry.

2.4.4.3.4.1 When Generated

The Mgmt_Bind_rsp is generated in response to a Mgmt_Bind_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned and all parameter fields after the Status field shall be omitted. Otherwise, the Remote Device shall implement the following processing.

Upon receipt of and after support for the Mgmt_Bind_req has been verified, the Remote Device shall perform an APSME-GET.request (for the *apsBindingTable* attribute) and process the resulting APSME-GET.confirm (containing the *apsBindingTable* attribute) to create the Mgmt_Bind_rsp command. The Mgmt_Bind_rsp command shall contain the same status that was contained in the APSME-GET.confirm primitive and if this was not SUCCESS, all parameter fields after the status field shall be omitted.

From the *apsBindingTable* attribute, the binding table shall be accessed, starting with the index specified by StartIndex, and moved to the BindingTableList field of the Mgmt_Bind_rsp command. The entries reported from the binding table shall be those, starting with StartIndex and including whole BindingTableList records (see Table 2.131) until the MSDU size limit, *i.e.*, *aMaxMACFrameSize* (see [B1]), is reached. Within the Mgmt_Bind_Rsp command, the BindingTableEntries field shall represent the total number of Binding Table entries in the Remote Device.

The BindingTableListCount field shall be the number of entries reported in the BindingTableList field of the Mgmt_Bind_req command.

2.4.4.3.4.2 Effect on Receipt

The local device is notified of the results of its attempt to obtain the binding table.

2.4.4.3.5 Mgmt_Leave_rsp

The Mgmt_Leave_rsp command (ClusterID=0x8034) shall be formatted as illustrated in Figure 2.98.

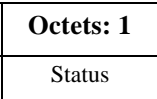


Figure 2.98 Format of the Mgmt_Leave_rsp Command Frame

Table 2.132 specifies the fields of the Mgmt_Leave_rsp command frame.

Table 2.132 Fields of the Mgmt_Leave_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED, NOT_AUTHORIZED or any status code returned from the NLME-LEAVE.confirm primitive	The status of the Mgmt_Leave_req command.

2.4.4.3.5.1 When Generated

The Mgmt_Leave_rsp is generated in response to a Mgmt_Leave_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned. Otherwise, the Remote Device shall implement the following processing.

Upon receipt of and after support for the Mgmt_Leave_req has been verified, the Remote Device shall execute the NLME-LEAVE.request to disassociate from the currently associated network. The Mgmt_Leave_rsp shall contain the same status that was contained in the NLME-LEAVE.confirm primitive.

Once a device has disassociated, it may execute pre-programmed logic to perform NLME-NETWORK-DISCOVERY and NLME-JOIN to join/re-join a network.

2.4.4.3.5.2 Effect on Receipt

The local device is notified of the results of its attempt to cause a remote device to leave the network.

2.4.4.3.6 Mgmt_Direct_Join_rsp

The Mgmt_Direct_Join_rsp (ClusterID=0x8035) shall be formatted as illustrated in Figure 2.99.

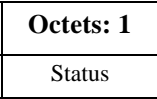


Figure 2.99 Format of the Mgmt_Direct_Join_rsp Command Frame

Table 2.133 specifies the fields of the Mgmt_Direct_Join_rsp command frame.

Table 2.133 Fields of the Mgmt_Direct_Join_rsp Command

Name	Type	Valid Range	Description
Status	Integer	NOT_SUPPORTED, NOT_AUTHORIZED or any status code returned from the NLME-DIRECT-JOIN.confirm primitive	The status of the Mgmt_Direct_Join_req command.

2.4.4.3.6.1 When Generated

The Mgmt_Direct_Join_rsp is generated in response to a Mgmt_Direct_Join_req. If this management command is not supported, a status of NOT_SUPPORTED shall be returned. Otherwise, the Remote Device shall implement the following processing.

Upon receipt and after support for the Mgmt_Direct_Join_req has been verified, the Remote Device shall execute the NLME-DIRECT-JOIN.request to directly associate the DeviceAddress contained in the Mgmt_Direct_Join_req to the network. The Mgmt_Direct_Join_rsp shall contain the same status that was contained in the NLME-DIRECT-JOIN.confirm primitive.

2.4.4.3.6.2 Effect on Receipt

Upon receipt and after support for the Mgmt_Direct_Join_req has been verified, the Remote Device shall execute the NLME-DIRECT-JOIN.request to directly associate the DeviceAddress contained in the Mgmt_Direct_Join_req to the network.

2.4.4.3.7 Mgmt_Permit_Joining_rsp

The Mgmt_Permit_Joining_rsp command (ClusterID=0x8036) shall be formatted as illustrated in Figure 2.100.

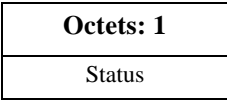


Figure 2.100 Format of the Mgmt_Permit_Joining_rsp Command Frame

Table 2.134 specifies the fields of the Mgmt_Permit_Joining_rsp command frame.

Table 2.134 Fields of the Mgmt_Permit_Joining_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS, INVALID_REQUEST, NOT_AUTHORIZED or any status code returned from the NLME-PERMIT-JOINING.confirm primitive	The status of the Mgmt_Permit_Joining_rsp command.

2.4.4.3.7.1 When Generated

The Mgmt_Permit_Joining_rsp is generated in response to a unicast Mgmt_Permit_Joining_req. In the description which follows, note that no response shall be sent if the Mgmt_Permit_Joining_req was received as a broadcast to all routers. If this management command is not permitted by the requesting device, a status of INVALID_REQUEST shall be returned. Upon receipt and after support for Mgmt_Permit_Joining_req has been verified, the Remote Device shall execute the NLME-PERMIT-JOINING.request. The Mgmt_Permit-Joining_rsp shall contain the same status that was contained in the NLME-PERMIT-JOINING.confirm primitive.

2.4.4.3.7.2 Effect on Receipt

The status of the Mgmt_Permit_Joining_req command is notified to the requestor.

2.4.4.3.8 Mgmt_Cache_rsp

The Mgmt_Cache_rsp command (ClusterID=0x8037) shall be formatted as illustrated in Figure 2.101

Octets: 1	1	1	1	Variable
Status	DiscoveryCacheEntries	StartIndex	DiscoveryCacheListCount	DiscoveryCacheList

Figure 2.101 Format of the Mgmt_Cache_rsp Command Frame

Table 2.135 specifies the fields of the Mgmt_Cache_rsp command frame.

Table 2.135 Fields of the Mgmt_Cache_rsp Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS or NOT_SUPPORTED	The status of the Mgmt_Cache_rsp command.
DiscoveryCacheEntries	Integer	0x00 - 0xff	DiscoveryCacheEntries.
StartIndex	Integer	0x00 - 0xff	StartIndex.
DiscoveryCacheListCount	Integer	0x00 - 0xff	The list shall contain the number of elements given by the DiscoveryCacheListCount parameter.
DiscoveryCacheList	Integer	List of DiscoveryCache descriptors	A list of descriptors, one for each of the Discovery cache devices registered, beginning with the StartIndex element and continuing for DiscoveryCacheListCount, of the registered devices in the Primary Discovery Cache. Each entry shall be formatted as illustrated in Table 2.136.

Table 2.136 DiscoveryCacheList Record Format

Name	Size (Bits)	Valid Range	Description
Extended Address	64	An extended 64-bit IEEE Address	64-bit IEEE Address of the cached device.
Network Address	16	Network address	The 16-bit network address of the cached device.

2.4.4.3.8.1 When Generated

The Mgmt_Cache_rsp is generated in response to an Mgmt_Cache_req. If this management command is not supported, or the Remote Device is not a Primary Cache Device, a status of NOT_SUPPORTED shall be returned and all parameter fields after the Status field shall be omitted. Otherwise, the Remote Device shall implement the following processing. Upon receipt of the Mgmt_Cache_req and after support for the Mgmt_Cache_req has been verified, the Remote Device shall access an internally maintained list of registered ZigBee End Devices utilizing the discovery cache on this Primary Discovery Cache device. The entries reported shall be those, starting with StartIndex and including whole DiscoveryCacheList records (see Table 2.139) until the limit on MSDU size, *i.e.*, *aMaxMACFrameSize* (see [B1]), is reached. Within the Mgmt_Cache_rsp command, the DiscoveryCacheListEntries field shall represent the total number of registered entries in the Remote Device. The parameter DiscoveryCacheListCount shall be the number of entries reported in the DiscoveryCacheList field of the Mgmt_Cache_rsp command.

2.4.4.3.8.2 Effect on Receipt

The local device is notified of the results of its attempt to obtain the discovery cache list.

2.4.4.3.9 Mgmt_NWK_Update_notify

The Mgmt_NWK_Update_notify command (ClusterID=0x8038) shall be formatted as illustrated in Figure 2.102.

Octets: 1	4	2	2	1	Variable
Status	ScannedChannels	TotalTransmissions	Transmission Failures	ScannedChannelsListCount	EnergyValues

Figure 2.102 Format of the Mgmt_NWK_Update_notify Command Frame

Table 2.137 specifies the fields of the Mgmt_NWK_Update_notify command frame.

Table 2.137 Fields of the Mgmt_NWK_Update_notify Command

Name	Type	Valid Range	Description
Status	Integer	SUCCESS,INVALID_REQUEST, NOT_SUPPORTED or any status values returned from the PLME-SET,confirm primitive ^a	The status of the Mgmt_NWK_Update_notify command.
ScannedChannels	Bitmap	0x00000000 - 0xffffffff.	List of channels scanned by the request.
TotalTransmissions	Integer	0x0000 -0xffff	Count of the total transmissions reported by the device.
TransmissionFailures	Integer	x0000 -0xffff	Sum of the total transmission failures reported by the device.
ScannedChannelsListCount	Integer	0x00 - 0xff	The list shall contain the number of records contained in the EnergyValues parameter.
EnergyValues	Integer	List of ED values each of which can be in the range of 0x00 - 0xff	The result of an energy measurement made on this channel in accordance with [B1].

a. ZigBee Document 12-0220-04

2.4.4.3.9.1 When Generated

The Mgmt_NWK_Update_notify is provided to enable ZigBee devices to report the condition on local channels to a network manager. The scanned channel list is the report of channels scanned and it is followed by a list of records, one for each channel scanned, each record including one byte of the energy level measured during the scan, or 0xff if there is too much interference on this channel.

When sent in response to a Mgmt_NWK_Update_req command the status field shall represent the status of the request. When sent unsolicited the status field shall be set to SUCCESS.

2.4.4.3.9.2 Effect on Receipt

The local device is notified of the local channel conditions at the transmitting device, or of its attempt to update network configuration parameters.

2.4.5 ZDP Enumeration Description

This sub-clause explains the meaning of the enumerations used in the ZDP. Table 2.138 shows a description of the ZDP enumeration values.

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Table 2.138 ZDP Enumerations Description

Enumeration	Value	Description
SUCCESS	0x00	The requested operation or transmission was completed successfully.
-	0x01-0x7f	Reserved.
INV_REQUESTTYPE	0x80	The supplied request type was invalid.
DEVICE_NOT_FOUND	0x81	The requested device did not exist on a device following a child descriptor request to a parent.
INVALID_EP	0x82	The supplied endpoint was equal to 0x00 or 0xff.
NOT_ACTIVE	0x83	The requested endpoint is not described by a simple descriptor.
NOT_SUPPORTED	0x84	The requested optional feature is not supported on the target device.
TIMEOUT	0x85	A timeout has occurred with the requested operation.
NO_MATCH	0x86	The end device bind request was unsuccessful due to a failure to match any suitable clusters.
-	0x87	Reserved.
NO_ENTRY	0x88	The unbind request was unsuccessful due to the coordinator or source device not having an entry in its binding table to unbind.
NO_DESCRIPTOR	0x89	A child descriptor was not available following a discovery request to a parent.
INSUFFICIENT_SPACE	0x8a	The device does not have storage space to support the requested operation.
NOT_PERMITTED	0x8b	The device is not in the proper state to support the requested operation.
TABLE_FULL	0x8c	The device does not have table space to support the operation.

Table 2.138 ZDP Enumerations Description (Continued)

Enumeration	Value	Description
NOT_AUTHORIZED	0x8d	The permissions configuration table on the target indicates that the request is not authorized from this device.
DEVICE_BINDING_TABLE_FULL	0x8e	The device does not have binding table space to support the operation.
-	0x8f-0xff	Reserved.

2.4.6 Conformance

When conformance to this Profile is claimed, all capabilities indicated mandatory for this Profile shall be supported in the specified manner (process mandatory). This also applies to optional and conditional capabilities, for which support is indicated, and is subject to verification as part of the ZigBee certification program.

2.5 The ZigBee Device Objects (ZDO)

2.5.1 Scope

This section describes the concepts, structures, and primitives needed to implement a ZigBee Device Objects application on top of a ZigBee Application Support Sub-layer (sub-clause 2.2) and ZigBee Network Layer (Chapter 3).

ZigBee Device Objects are applications which employ network and application support layer primitives to implement ZigBee End Devices, ZigBee Routers, and ZigBee Coordinators.

The ZigBee Device Object Profile employs Clusters to describe its primitives. The ZigBee Device Profile Clusters do not employ attributes and are analogous to messages in a message transfer protocol. Cluster identifiers are employed within the ZigBee Device Profile to enumerate the messages employed within ZigBee Device Objects.

ZigBee Device Objects also employ configuration attributes. The configuration attributes within ZigBee Device Objects are attributes set by the application or stack profile. The configuration attributes are also not related to the ZigBee Device Profile, though both the configuration attributes and the ZigBee Device Profile are employed with ZigBee Device Objects.

2.5.2 Device Object Descriptions

The ZigBee Device Objects are an application solution residing within the Application Layer (APL) and above the Application Support Sub-layer (APS) in the ZigBee stack architecture as illustrated in Figure 1.1.

The ZigBee Device Objects are responsible for the following functions:

- Initializing the Application Support Sublayer (APS), Network Layer (NWK), Security Service Provider (SSP) and any other ZigBee device layer other than the end applications residing over Endpoints 1-254.
- Assembling configuration information from the end applications to determine and implement the functions described in the following sub-clauses.

2.5.2.1 Primary Discovery Cache Device Operation

The Primary Discovery Cache device is designated through configuration of the device and advertisement in the Node Descriptor. The Primary Discovery Cache device operates as a state machine with respect to clients wishing to utilize the services of the Primary Discovery Cache. The following states and operations, as described in Figure 2.103, shall be supported by the Primary Discovery Cache device:

- Undiscovered:
 - The client employs the Find Node Cache request, broadcast to all devices for which `macRxOnWhenIdle=TRUE` to determine if there is an existing discovery cache entry for the Local Device. If a discovery cache device responds to the request, the Local Device may update the discovery information and shall transition to the Registered state.
 - The client employs the radius limited message System Server Discovery request, broadcast to all devices for which `macRxOnWhenIdle = TRUE`, to locate a Primary Discovery Cache device within the radius supplied by the request.
- Discovered:
 - The client employs the unicast Discovery store request directed to the Discovery Cache device containing the sizes of the discovery cache information it wishes to store. The Discovery Cache Device will respond with a `SUCCESS`, `INSUFFICIENT_SPACE` or `NOT_SUPPORTED`.
- Registered:
 - This state is reached when a `SUCCESS` status was received by the client from the Discovery Cache device from a previous Discovery cache request or the Find Node Cache request found a pre-existing discovery cache entry. The client must now upload its discovery information using the Node

- Descriptor store request, Power Descriptor store request, Active Endpoint store request, and Simple Descriptor store requests to enable the Primary Discovery Cache device to fully respond on its behalf.
- Unregistered:
 - The client (or any other device) may request to be unregistered. The Remove Node Cache request removes the device from the Primary Discovery Cache device. The Primary Cache Device responds to device and service discovery requests for all registered clients it supports. The Find Node Cache request is employed by clients wanting to locate the device and service discovery location for a given device of interest. Note that if the discovery information is held by the device itself, that device must also respond to identify itself as the repository of discovery information. See Figure 2.103 for details on state machine processing for the Primary Discovery Cache device.

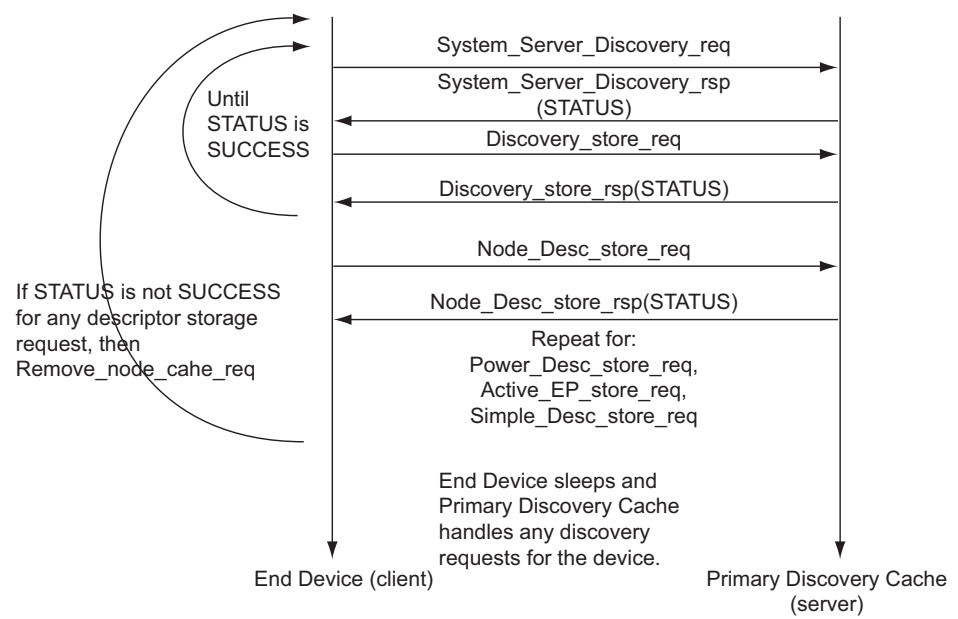


Figure 2.103 Primary Discovery Cache State Machine

2.5.2.2 Device and Service Discovery

This function shall support device and service discovery within a single PAN. Additionally, for all ZigBee device types, this function shall perform the following:

- Within each network employing sleeping ZigBee End Devices, some ZigBee Routers (or the ZigBee Coordinator) may be designated as Primary Discovery

Cache Devices as described by their Node Descriptor. These Primary Cache Devices are themselves discoverable and provide server services to upload and store discovery information on behalf of sleeping ZigBee End Devices. Additionally, the Primary Cache Devices respond to discovery requests on behalf of the sleeping ZigBee End Devices. Each Primary Discovery Cache Device shall be either a ZigBee Router or the ZigBee Coordinator.

- For ZigBee End Devices which intend to sleep as indicated by: Config_Node_Power, Device and Service Discovery may manage upload and storage of the NWK Address, IEEE Address, Active Endpoints, Simple Descriptors, Node Descriptor, and Power Descriptor onto a Primary Discovery Cache device selected by the ZigBee End Device to permit device and service discovery operations on these sleeping devices.
- For the ZigBee Coordinator and ZigBee Routers designated as Primary Discovery Cache Devices, this function shall respond to discovery requests on behalf of sleeping ZigBee End Devices who have registered and uploaded their discovery information.
- For all ZigBee devices, Device and Service Discovery shall support device and service discovery requests from other devices and permit generation of requests from their local Application Objects. Note that Device and Service Discovery services may be provided by the Primary Discovery Cache devices on behalf of other ZigBee End Devices. In cases where the Primary Discovery Cache Device is the target of the request, the NWKAddrOfInterest or Device of Interest fields shall be filled in the request and/or response to differentiate the target of the request from the device that is the target of discovery. The following discovery features shall be supported:
 - Device Discovery:
 - Based on a unicast inquiry of a ZigBee Coordinator or ZigBee Router's IEEE address, the IEEE Address of the requested device plus, optionally, the NWK Addresses of all associated devices shall be returned.
 - Based on a unicast inquiry of a ZigBee End Device's IEEE address, the IEEE Address of the requested device shall be returned.
 - Based on a broadcast inquiry (of any broadcast address type) of a ZigBee Coordinator or ZigBee Router's NWK Address with a supplied IEEE Address, the NWK Address of the requested device plus, optionally, the NWK Addresses of all associated devices shall be returned.
 - Based on a broadcast inquiry (of any broadcast address type) of a ZigBee End Device's NWK Address with a supplied IEEE Address, the NWK Address of the requested device shall be returned. The responding

device shall employ APS acknowledged service for the unicast response to the broadcast inquiry.

- Service Discovery: Based on the following inputs, the corresponding responses shall be supplied:
 - NWK address plus Active Endpoint query type – Specified device shall return the endpoint number of all applications residing in that device. Should the list of active endpoints exceed the ASDU size and where fragmentation is not supported on the server device, an extended version of the query type is also provided to return the full list through multiple requests.
 - NWK address or broadcast address (of any broadcast address type) plus Service Match including Profile ID and, optionally, Input and Output Clusters – Specified device matches Profile ID with all active endpoints to determine a match. If no input or output clusters are specified, the endpoints that match the request are returned. If input and/or output clusters are provided in the request, those are matched as well, and any matches are provided in the response with the list of endpoints on the device providing the match. The responding device shall employ APS acknowledged service for the unicast response to the broadcast inquiry. By convention, in cases where the application profile enumerates input clusters and their response output clusters with the same cluster identifier, the application profile shall list only the input cluster within the Simple Descriptor for the purposes of Service Discovery.
 - NWK address plus Node Descriptor or Power Descriptor query type – Specified device shall return the Node or Power Descriptor for the device.
 - NWK address, Endpoint Number plus Simple Descriptor query type – Specified address shall return the Simple Descriptor associated with that Endpoint for the device. Should the list of input and/or output clusters exceed the ASDU size capacity to return the Simple Descriptor in a single packet an extended version of the query type is also provided to return the full list through multiple requests.
 - Optionally, NWK address plus Complex or User Descriptor query type – If supported, specified address shall return the Complex or User Descriptor for the device

2.5.2.3 Security Manager

This function determines whether security is enabled or disabled and, if enabled, shall perform the following:

- Establish Key
- Transport Key
- Request Key
- Update Device
- Remove Device
- Switch Key
- Authenticate Device

The Security Manager function addresses the Security Services Specification (Chapter 4). Security Management, implemented by APSME primitive calls by ZDO, performs the following:

- Contacts the Trust Center to obtain the Master Key between this device and the Trust Center (step is omitted if this device is the Trust Center, the Master Key with the Trust Center has been pre-configured, or the network is operating in residential mode). This step employs the Transport Key primitive.
- Establishes a Link Key with the Trust Center. This step employs the APSME-ESTABLISH-KEY primitive (omitted in residential mode).
- Obtains the NWK Key from the Trust Center using secured communication with the Trust Center (commercial mode). Alternatively, the NWK Key from the Trust Center may be sent from the Trust Center using unsecured communication (residential mode). This step employs the APSME-TRANSPORT-KEY primitive.
- Establishes or transports Link Keys and master keys, as required, with specific devices in the network identified as messaging destinations (commercial mode). These steps employ the APSME-ESTABLISH-KEY, APSME-TRANSPORT-KEY and/or APSME-REQUEST-KEY primitives.
- Informs the Trust Center of any devices that join the network using the APSME-UPDATE-DEVICE primitives. This function is only performed if the device is a ZigBee router.
- Permits devices to obtain keys from the Trust Center using the APSME-REQUEST-KEY primitives.
- Permits the Trust Center to remove devices from the network using the APSME-REMOVE-DEVICE primitives.

- Permits the Trust Center to switch the active network key using the APSME-SWITCH-KEY primitives.
- Permits devices in the network to authenticate other devices using the APSME-AUTHENTICATE primitives.

2.5.2.4 Network Manager

This function shall implement the ZigBee Coordinator, ZigBee Router, or ZigBee End Device logical device types according to configuration settings established either via a programmed application or during installation. If the device type is a ZigBee Router or ZigBee End Device, this function shall provide the ability to select an existing PAN to join and implement procedures which permit the device to rejoin if network communication is lost. If the device type is a ZigBee Coordinator or ZigBee Router, this function shall provide the ability to select an unused channel for creation of a new PAN. Note that it is possible to deploy a network without a device pre-designated as ZigBee Coordinator where the first Full Function Device (FFD) activated assumes the role of ZigBee Coordinator. The following description covers processing addressed by Network Management:

- Permits specification of a channel list for network scan procedures. Default is to specify use of all channels in the selected band of operation.
- Manages network scan procedures to determine neighboring networks and the identity of their ZigBee coordinators and routers.
- Permits selection of a channel to start a PAN (ZigBee Coordinator) or selection of an existing PAN to join (ZigBee Router or ZigBee End Device).
- Supports orphaning and extended procedures to rejoin the network, including support for intra_PAN portability.
- May support direct join. For ZigBee Coordinators and ZigBee Routers, a local version of direct join may be supported to enable the device to join via the orphaning or rejoin procedures.
- May support Management Entities that permit external network management.
- Detects and reports interference to support changing network channels.
- Manages network interference reporting and selection of a new channel for network operation if interference exists on the initial channel if the particular node is identified as the network manager for the overall PAN.

2.5.2.5 Binding Manager

The Binding Manager performs the following:

- Establishes resource size for the Binding Table. The size of this resource is determined via a programmed application or via a configuration attribute defined during installation. 1
- Processes bind requests for adding or deleting entries from the APS binding table. 2
- Supports Bind and Unbind commands from external applications such as those that may be hosted on a commissioning or network management tool to support assisted binding. Bind and Unbind commands shall be supported via the ZigBee Device Profile (see clause 2.4). 3
- For the ZigBee Coordinator, supports the End Device Bind that permits binding on the basis of button presses or other manual means. 4
- Permits source devices to register with a primary binding table cache their ability to hold their own binding table. 5
- Permits configuration tools to exchange one device for another in all the binding table entries which refer to it. 6
- Permits the primary binding table cache to backup and recover individual bind entries or the entire binding table or the table of source devices holding their own binding tables. 7

2.5.2.6 Node Manager 8

For ZigBee Coordinators and ZigBee Routers, the Node Management function performs the following: 9

- Permits remote management commands to perform network discovery. 10
- Provides remote management commands to retrieve the routing table. 11
- Provides remote management commands to retrieve the binding table. 12
- Provides a remote management command to have the device leave the network or to direct that another device leave the network. 13
- Provides a remote management command to retrieve the LQI for neighbors of the remote device. 14
- Provides a remote management command to Permit or disallow joining on particular routers or to generally allow or disallow joining via the Trust Center. 15

2.5.2.7 Group Manager 16

The Group Manager performs the following: 17

- Provides for inclusion of application objects within the local device into groups under application control. 18

- Provides for removal of application objects within the local device from group membership under application control.

2.5.3 Layer Interface Description

Unlike other device descriptors for applications residing above Endpoints 1-254, the ZigBee Device Objects (ZDO) interface to the APS via the APSME-SAP in addition to the APSDE-SAP. ZDO communicates over Endpoint 0 using the APSDE-SAP via Profiles like all other applications. The Profile used by ZDO is the ZigBee Device Profile (See clause 2.4). ZDO frames shall not be fragmented.

ZigBee Device Objects shall employ Endpoint 0 as the source and destination endpoint in any transmitted ZigBee Device Profile request frames, and shall expect Endpoint 0 as the source and destination endpoint in any received response frames.

2.5.4 System Usage

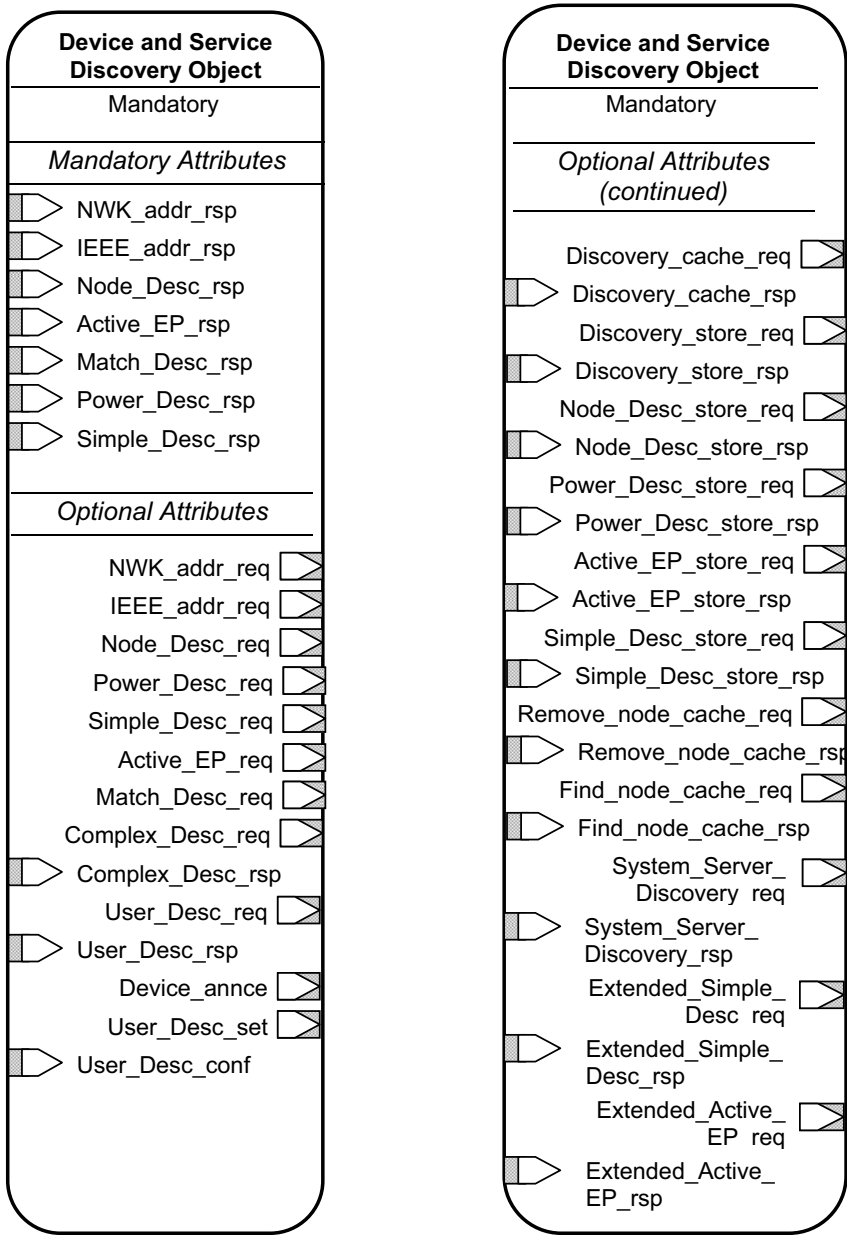


Figure 2.104 System Usage ZigBee Device Object Details

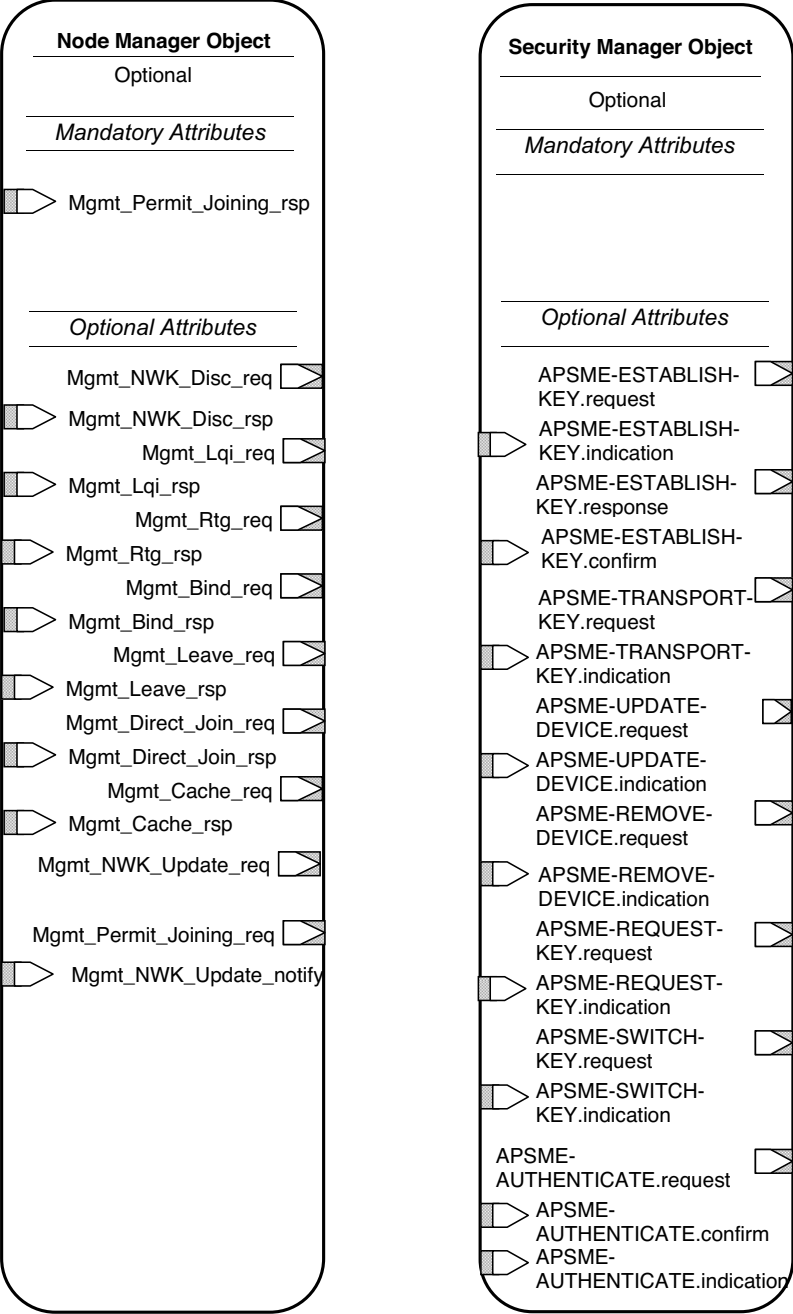


Figure 2.105 System Usage ZigBee Device Object Details — Node Manager Object and Security Manager Object

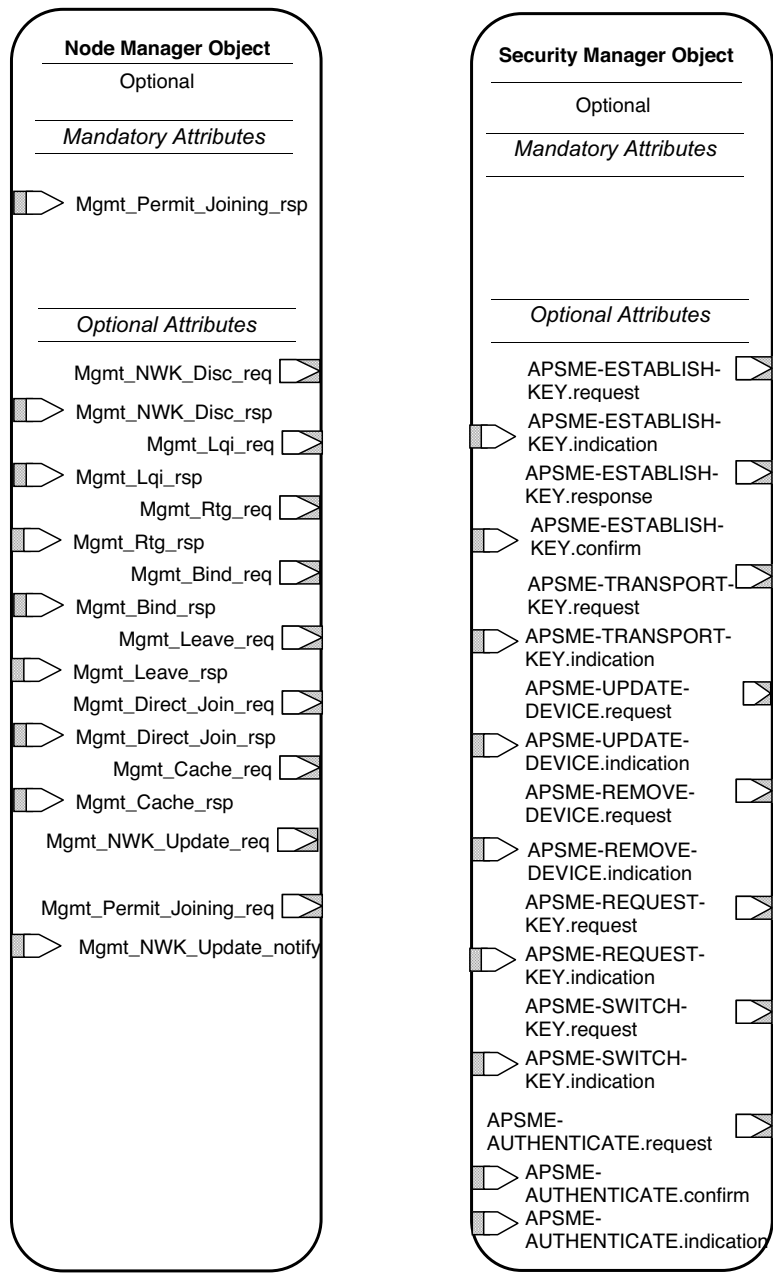


Figure 2.106 System Usage ZigBee Device Object Details — Binding Manager Object and Network Manager Object

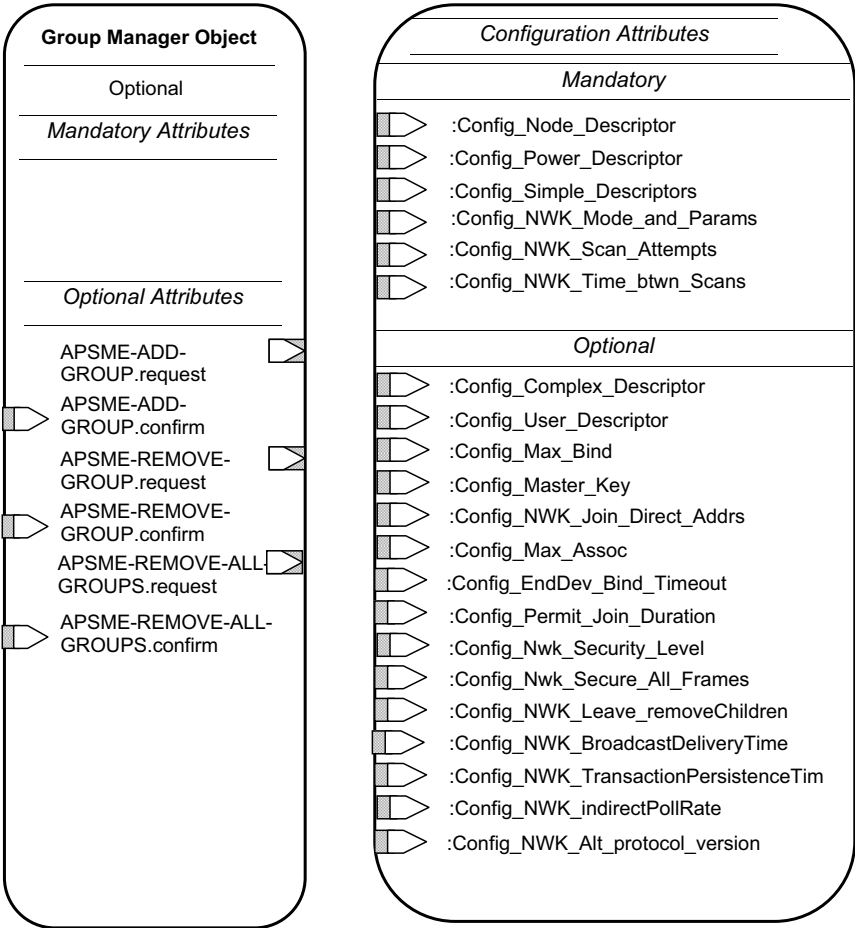


Figure 2.107 System Usage ZigBee Device Object Details — Group Manager Object and Configuration Attributes

2.5.5 Object Definition and Behavior

2.5.5.1 Object Overview

ZigBee Device Objects contain six Objects:

- Device and Service Discovery
- Network Manager
- Binding Manager
- Security Manager

- Node Manager
- Group Manager

Table 2.139 describes these ZigBee Device Objects.

Table 2.139 ZigBee Device Objects

Object		Description
Name	Status	
:Device_and_Service_Discovery	M	Handles device and service discovery.
:Network_Manager	M	Handles network activities such as network discovery, leaving/joining a network, resetting a network connection and creating a network.
:Binding_Manager	O	Handles end device binding, binding and unbinding activities.
:Security_Manager	O	Handles security services such as key loading, key establishment, key transport and authentication.
:Node_Manager	O	Handles management functions.
:Group Manager	O	Handles management of groups

2.5.5.2 Optional and Mandatory Objects and Attributes

Objects listed as Mandatory shall be present on all ZigBee devices. However, for certain ZigBee logical types, Objects listed as Optional for all ZigBee devices may be Mandatory in specific logical device types. For example, the NLME-NETWORK-FORMATION.request within the Network_Manager object is in a Mandatory object and is an Optional attribute, though the attribute is required for ZigBee Coordinator logical device types. The introduction section of each Device Object section will detail the support requirements for Objects and Attributes by logical device type.

2.5.5.3 Security Key Usage

ZigBee Device Objects may employ security for packets created by ZigBee Device Profile primitives. These application packets using APSDE on Endpoint 0 shall utilize the APSDE Security Service Provider interface like all other Application Objects.

2.5.5.4 Public and Private Methods

Methods that are accessible to any endpoint application on the device are called public methods. Private methods are only accessible to the Device Application on

endpoint 0 and not to the end applications (which run on endpoints 1 through 254).

2.5.5.5 State Machine Functional Descriptions

2.5.5.5.1 ZigBee Coordinator

2.5.5.5.1.1 Initialization

The implementation shall set the startup-related IB attributes shown in Table 2.140 to values that reflect the desired startup behavior for the device. In particular, the *apsDesignatedCoordinator* attribute of the IB shall be set to TRUE. If the device implements more than one option for ZigBee protocol version or stack profile, it shall choose a single value for each and set *nwkProtocolVersion* and *nwkStackProfile* accordingly. Additionally, provision shall be made to provide configuration elements to describe the Node Descriptor, Power Descriptor, Simple Descriptor for each active endpoint and application plus the list of active endpoints. These configurations shall be embodied in :Config_Node_Descriptor, :Config_Power_Descriptor, and :Config_Simple_Descriptors. If the :Config_Node_Descriptor configuration object indicates that this device is a Primary Discovery Cache device, the device shall be configured to process server commands for the ZigBee Device Profile associated with requests to the Primary Discovery Cache and shall operate according to the state machine description provided in sub-clause 2.5.2.1.

If supported, provision shall be made to supply configuration elements for the Complex Descriptor, User Descriptor, the maximum number of bind entries and the master key. These elements shall be embodied in :Config_Complex_Descriptor, :Config_User_Descriptor, :Config_Max_Bind and :Config_Master_Key.

To start as a ZigBee coordinator, the device application shall execute the startup procedure described in sub-clause 2.5.5.5.6.2 with startup attributes set as described above. This should have the effect of executing the procedure for network formation described in sub-clause 3.6.1.1. The device application shall set the *nwkSecurityLevel*, *nwkAllFresh*, and *nwkSecureAllFrames* NIB attributes according to the values established by convention within the Stack Profile employed by the device. The device application shall check the return status via the NLME-NETWORK-FORMATION.confirm to verify successful creation of the PAN. The :Config_Permit_Join_Duration shall be set according to the default attribute value supplied using the NLME-PERMIT-JOINING.request. Additionally, the *nwkNetworkBroadcastDeliveryTime* and *nwkTransactionPersistenceTime* Network Information Block attributes (see sub-clause 3.6.2) shall be set with :Config_NWK_BroadcastDeliveryTime and :Config_NWK_TransactionPersistenceTime respectively (see sub-clause 2.5.6).

Provision shall be made to ensure APS primitive calls from the end applications over EP 1 through EP 254 return appropriate error status values prior to

completion of the Initialization state by ZigBee Device Objects and transition to the normal operating state.

2.5.5.5.1.2 Normal Operating State

In this state, the ZigBee Coordinator shall process the list of direct joined addresses in :Config_NWK_Join_Direct_Addrs by issuing an NLME-DIRECT-JOIN.request for each included address in the list. Processing of the direct joined addresses shall employ the :Config_Max_Assoc attribute in evaluating whether to successfully process a direct joined address within :Config_NWK_Join_Direct_Addrs.

The ZigBee coordinator shall allow other devices to join the network based on the configuration items :Config_Permit_Join_Duration and :Config_Max_Assoc. When a new device joins the network, the device application shall be informed via the NLME-JOIN.indication. Should the device be admitted to the PAN, the ZigBee coordinator shall indicate this via the NLME-JOIN.confirm with SUCCESS status.

The ZigBee coordinator shall respond to any device discovery or service discovery operations requested of its own device, and if it is designated as a Primary Discovery Cache device, shall also respond on behalf of registered devices that have stored discovery information. The device application shall also ensure that the number of binding entries does not exceed the :Config_Max_Bind attribute.

The ZigBee coordinator shall support the NLME-PERMIT-JOINING.request and NLME-PERMIT-JOINING.confirm to permit application control of network join processing.

The ZigBee coordinator shall support the NLME-LEAVE.request and NLME-LEAVE.indication employing the :Config_NWK_Leave_removeChildren attribute where appropriate to permit removal of associated devices under application control. Conditions that lead to removal of associated devices may include lack of security credentials, removal of the device via a privileged application or detection of exception.

The ZigBee coordinator shall maintain a list of currently associated devices and facilitate support of orphan scan and rejoin processing to enable previously associated devices to rejoin the network. The ZigBee coordinator may support the ability for devices to be directly included in the network via the NLME-DIRECT-JOIN.request and NLME-DIRECT-JOIN.confirm. This feature shall permit lists of ZigBee IEEE addresses to be provided to the ZigBee coordinator and for those addresses to be included as previously associated devices. It shall be possible for ZigBee devices with those addresses to directly join the network via orphaning or rejoin procedures rather than associating directly.

The ZigBee coordinator shall support the NLME-NWK-STATUS.indication and process those notifications per clause 3.2.2.30.

The ZigBee coordinator shall process End_Device_Bind_req from ZigBee Routers and ZigBee End Devices. Upon receipt of an End_Device_Bind_req, the ZigBee Coordinator shall use the :Config_EndDev_Bind_Timeout value in the attribute and await a second End_Device_Bind_req. Should the second indication arrive within the timeout period, the ZigBee coordinator shall match the Profile ID in the two indications. If the Profile IDs in the two indications do not match, an appropriate error status is returned to each device via End_Device_Bind_rsp. Should the Profile IDs match, the ZigBee Coordinator shall match the AppInClusterLists and AppOutClusterLists in the two indications. Cluster IDs in the AppInClusterList of the first indication which match Cluster IDs in the AppOutClusterList of the second indication shall be saved in a list for inclusion in the resulting Bind_req notifying the devices of the match.

The ZigBee coordinator shall process Device_annce messages from other ZigBee devices. Upon receipt of a Device_annce where *nwkUseTreeRouting* is TRUE, the ZigBee coordinator shall check all internal tables holding 64-bit IEEE addresses for devices within the PAN for a match with the address supplied in the Device_annce message. If a match is detected, the ZigBee coordinator shall update its *nwkAddressMap* attribute of the NIB corresponding to the matched 64-bit IEEE address to reflect the updated 16-bit NWK address contained in the Device_annce. Upon receipt of a Device_annce where *nwkUseTreeRouting* is FALSE, the ZigBee Coordinator shall employ the address conflict resolution procedure detailed in sub-clause 3.6.9.

The ZigBee coordinator may generate APSME-AUTHENTICATE.requests under application control from other application objects, and may process and respond to APSME-AUTHENTICATE.indications from other devices. The ZigBee coordinator shall supply APSME-AUTHENTICATE.confirms to application objects whose requests have been processed.

2.5.5.5.1.3 Trust Center Operation

The network device pointed to by the address in *apsTrustCenterAddress* shall function as the Trust Center when security is enabled on the network.

The Trust Center operation is defined within sub-clause 4.6.2.

2.5.5.5.2 ZigBee Router

2.5.5.5.2.1 Initialization

The implementation shall set the startup-related IB attributes shown in Table 2.140 to values that reflect the desired startup behavior for the device. In particular, the *apsDesignatedCoordinator* attribute of the IB shall be set to FALSE. If the :Config_Node_Descriptor configuration object indicates that this device is a

Primary Discovery Cache device, the device shall be configured to process server commands for the ZigBee Device Profile associated with requests to the Primary Discovery Cache and shall operate according to the state machine description provided in sub-clause 2.5.2.1.

If supported, provision shall be made to supply configuration elements for the Complex Descriptor, User Descriptor, the maximum number of bind entries, and the master key. These elements shall be embodied in :Config_Complex_Descriptor, :Config_User_Descriptor, :Config_Max_Bind and :Config_Master_Key.

To start as a ZigBee router, the device application shall execute the startup procedure described in sub-clause 2.5.5.5.6.2 with startup attributes set as described above. This should have the effect of executing either the procedure for network rejoin described in sub-clause 3.6.1.4.2 or else the full procedure for network join through MAC association described in sub-clause 3.6.1.4.1. The NLME-NETWORK-DISCOVERY.request procedure shall be implemented :Config_NWK_Scan_Attempts, each separated in time by :Config_NWK_Time_btwn_Scans. The purpose of repeating the NLME-NETWORK-DISCOVERY.request is to provide a more accurate neighbor list and associated link quality indications to the NWK layer. Specification of the algorithm for selection of the PAN shall be left to the profile description and may include use of the Extended PAN ID, operational mode of the network, identity of the ZigBee Router or Coordinator identified on the PAN, depth of the ZigBee Router on the PAN from the ZigBee Coordinator for the PAN, capacity of the ZigBee Router or Coordinator, the routing cost, or the Protocol Version Number (these parameters are supplied by the NLME-NETWORK-DISCOVERY.confirm and the beacon payload).

The ZigBee router may join networks employing the current protocol version number or may join networks employing a previous protocol version number, under application control, if backward compatibility is supported in the device. A single ZigBee PAN shall consist of devices employing only a single protocol version number (networks with devices employing different protocol version numbers and frame formats within the same PAN are not permitted). An optional configuration attribute, :Config_NWK_alt_protocol_version, provides the protocol version numbers which the device may choose to employ other than the current protocol version number. Once the ZigBee router chooses a PAN and a specific protocol version number, it shall employ that protocol version number as its *nwkProtocolVersion*. Additionally, the ZigBee router shall then adhere to all frame formats and processing rules supplied by the version of the ZigBee Specification employing that protocol version number.

The :Config_Permit_Join_Duration shall be set according to the default parameter value supplied using NLME-PERMIT-JOINING.request. The router shall support the NLME-START-ROUTER.request and NLME-START-ROUTER.confirm to

begin operations as a router within the PAN it has joined. Additionally, the *nwkNetworkBroadcastDeliveryTime* and *nwkTransactionPersistenceTime* Network Information Block attributes (see sub-clause 3.6.2) shall be set with :Config_NWK_BroadcastDeliveryTime and :Config_NWK_TransactionPersistenceTime respectively (see sub-clause 2.5.6).

Provision shall be made to ensure APS primitive calls from the end applications over EP 1 through EP 254 return appropriate error status values prior to completion of the Initialization state by ZigBee Device Objects and transition to the normal operating state.

If the network has security enabled, the device shall wait to be authenticated by the Trust Center, and for successful acquisition of the NWK key to start functioning as a router in the network. See sub-clause 4.6.2 for details on Trust Center operations.

The device application shall set the *nwkSecurityLevel* and *nwkSecureAllFrames* NIB attributes to the values used in the network and begin functioning as a router using NLME-START-ROUTER.req.

2.5.5.5.2.2 Normal Operating State

In this state, the ZigBee router shall allow other devices to join the network based on the configuration items :Config_Permit_Join_Duration and :Config_Max_Assoc. When a new device joins the network, the device application shall be informed via the NLME-JOIN.indication attribute. Should the device be admitted to the PAN, the ZigBee router shall indicate this via the NLME-JOIN.confirm with SUCCESS status. If security is enabled on the network, the device application shall inform the Trust Center via the APSME-UPDATE-DEVICE.request.

Orphan indications for which this device is not the parent are notified to the ZDO from the NWK layer by receipt of an NLME-JOIN.indication primitive with parameter IsParent set to value FALSE. The mechanism by which this is handled is described in 2.5.5.5.4.

The ZigBee router shall respond to any device discovery or service discovery operations requested of its own device, and if it is designated as a Primary Discovery Cache device, shall also respond on behalf of registered devices that have stored discovery information. The device application shall also ensure that the number of binding entries does not exceed the :Config_Max_Bind attribute.

If security is supported operating in commercial mode, the ZigBee router shall support the :Config_Master_Key and shall employ the Master Key in key establishment procedures for Link Keys. Upon presentation of a remote destination address requiring secure communications, the ZigBee router shall support APSME-ESTABLISH-KEY.request to establish a link key with the remote device and APSME-ESTABLISH-KEY.indication to present the request to

the destination and shall support APSME-ESTABLISH-KEY.confirm and APSME-ESTABLISH-KEY.response to complete the key establishment of the Link Key. The ZigBee router shall provide the ability to store Link Keys for known destinations requiring secure communications and shall manage key storage of Link Keys. The ZigBee router shall support APSME-TRANSPORT-KEY.indication to receive keys from the Trust Center.

If security is supported operating in commercial or residential modes, the ZigBee router shall request the Trust Center to update its NWK key via the APSME-REQUEST-KEY.request.

The ZigBee router shall support the NLME-PERMIT-JOINING.request and NLME-PERMIT-JOINING.confirm to permit application control of network join processing.

The ZigBee router shall support the NLME-NWK-STATUS.indication and process those notifications per sub-clause 3.2.2.30.

The ZigBee router shall support the NLME-LEAVE.request and NLME-LEAVE.confirm employing the :Config_NWK_Leave_removeChildren attribute where appropriate to permit removal of associated devices under application control. Conditions that lead to removal of associated devices may include lack of security credentials, removal of the device via a privileged application or detection of exception.

The ZigBee router shall process Device_annce messages from other ZigBee devices. Upon receipt of a Device_annce where *nwkUseTreeRouting* is TRUE, the ZigBee router shall check all internal tables holding 64-bit IEEE addresses for devices within the PAN for a match with the address supplied in the Device_annce message. If a match is detected, the ZigBee router shall update its *nwkAddressMap* of the NIB corresponding to the matched 64-bit IEEE address to reflect the updated 16-bit NWK address contained in the Device_annce. Upon receipt of a Device_annce where *nwkUseTreeRouting* is FALSE, the ZigBee Router shall employ the address conflict resolution procedure detailed in sub-clause 3.6.9.

The ZigBee router shall maintain a list of currently associated devices and facilitate support of orphan scan and rejoin processing to enable previously associated devices to rejoin the network.

The ZigBee router may generate APSME-AUTHENTICATE.requests under application control from other application objects and may process and respond to APSME-AUTHENTICATE.indications from other devices. The ZigBee router shall supply APSME-AUTHENTICATE.confirms to application objects whose requests have been processed.

The ZigBee router may decide it has lost contact with the network it was joined to. In this situation, the router should conduct an active scan to find the network. If

the network is found more than once the router should attempt to rejoin where there is a more recent value of *nwkUpdateId* in the beacon payload.

2.5.5.5.3 Binding Table Cache Operation

Any router (including the coordinator) may be designated as either a primary binding table cache or a backup binding table cache.

It shall respond to the *System_Server_Discovery_req* primitive to enable other devices to discover it and use its facilities.

A primary binding table cache shall maintain a binding table and a table of devices registered to cache their binding tables.

A primary binding table cache shall respond to the *Bind_Register_req* and *Replace_Device_req* primitives described in clause 2.4.3.2.

If a backup binding table cache is available, a primary binding table cache shall use the additional bind management primitives to backup and restore its binding table and its table of source binding devices.

A backup binding table cache shall maintain a backup of the binding table and table of registered binding devices for one or more primary binding table caches. It shall support the bind management primitives for backup and restore of these tables.

2.5.5.5.4 Operations to Support Intra-PAN Portability

2.5.5.5.4.1 Overview

The operations described in this section are carried out by ZigBee Coordinator and ZigBee Router Devices for support of intra-PAN portability.

The main steps are summarized as follows:-

- Detect the problem - The ZDO of the moved device is notified of acknowledgement failures via the *NLME-NWK-STATUS.indication* primitive, and identifies a problem.
- Carry out the NWK layer rejoin procedure - The ZDO of a moved ZED initiates this process using the *NLME-JOIN.request* primitive, either through a secured or un-secured rejoining procedure. The NWK rejoin procedures closely mirror the MAC association procedure. Note that ZigBee Routers shall also carry out this procedure periodically if they find that they are no longer in contact with the Trust Center.
- Security verification - Secured and unsecured protocol steps are described to ensure that the orphaned device should really be accepted. (See clause 2.5.5.5.4.2.)

- Inform the rest of the network - when a device changes parents the steps to complete address conflict detection in sub-clause 3.6.1.9 must be completed. These actions also serve to notify the old parent that the End Device has changed parents.

These steps are described in detail in the subsections below. The mechanism is illustrated for secured rejoin of a ZED in Figure 2.108, trust center rejoin of a ZED in Figure 2.109, and trust center rejoin of a ZR in Figure 2.110 respectively. Note that the NWK and SEC sections on secured and trust center rejoin (sub-clauses 3.2.2.11, 3.2.2.12, 3.2.2.13, 3.6.1.4 and 4.6.3) shall be the authoritative text for these procedures. The diagrams in this section are provided for illustrative purposes only.

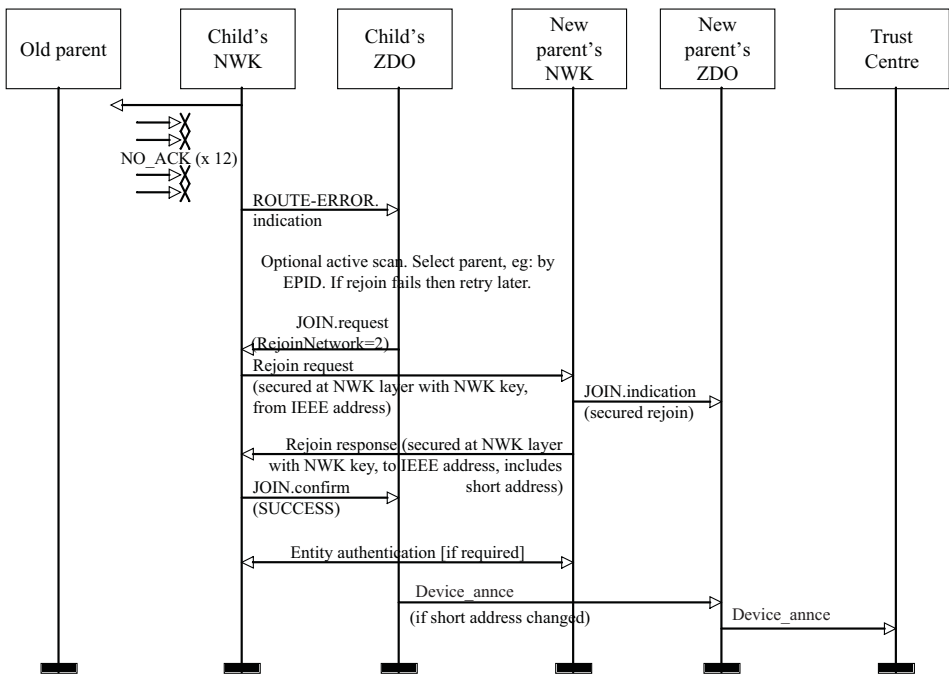


Figure 2.108 Portability Message Sequence Chart: ZED Secured Rejoin

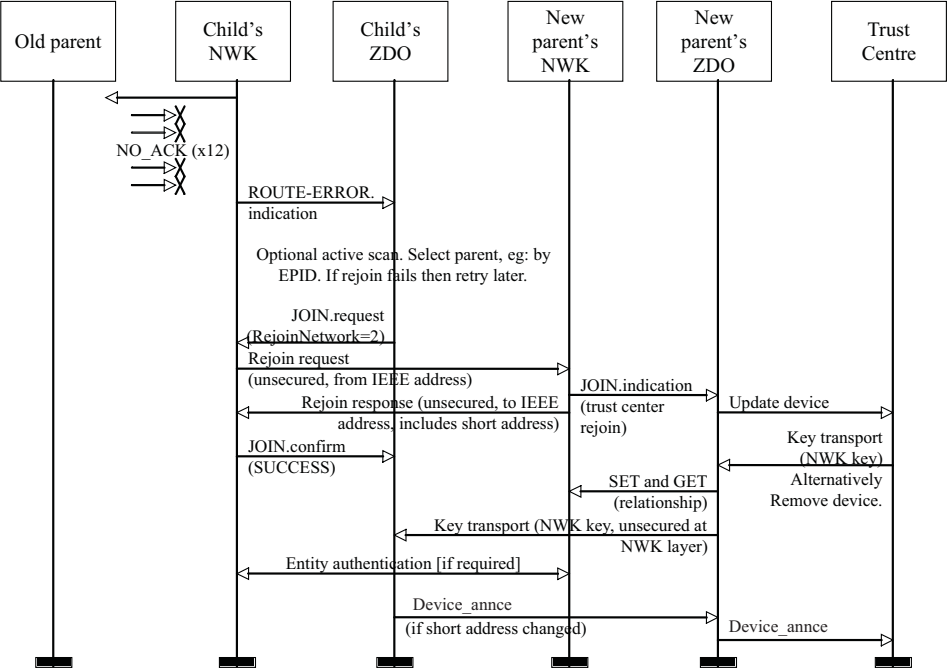


Figure 2.109 Portability Message Sequence Chart: ZED Trust Center Rejoin

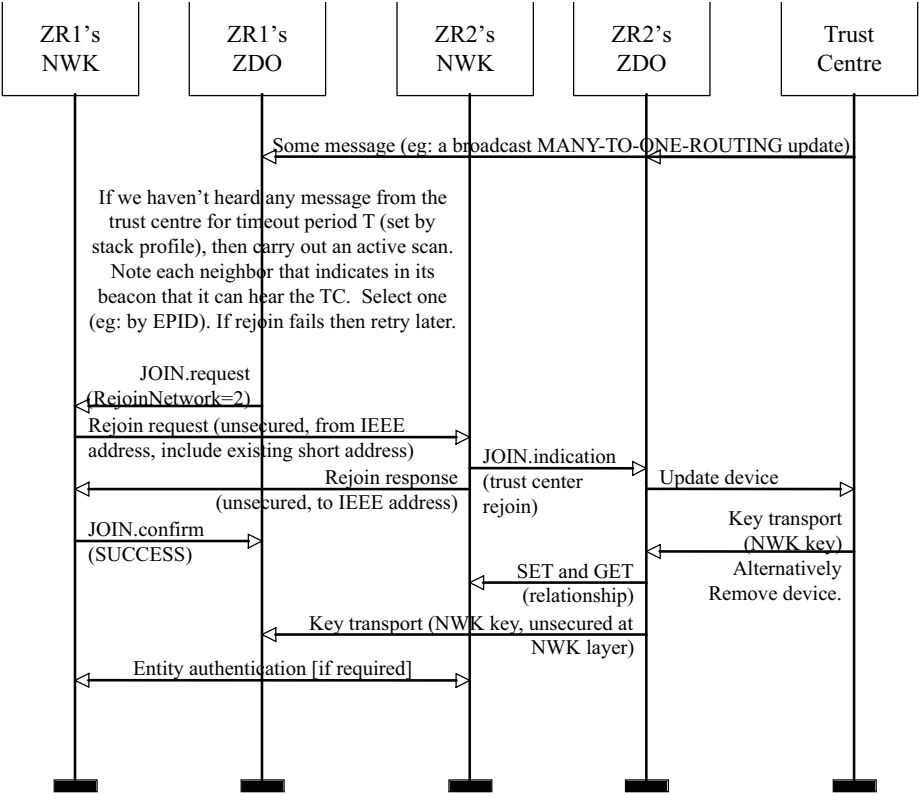


Figure 2.110 Portability Message Sequence Chart: ZR Trust Center Rejoin

2.5.5.5.4.2 Description of Operations for Security Verification

As for MAC association, a ZigBee Coordinator or ZigBee Router device is informed of a rejoined device when the NLME issues an NLME-JOIN.indication primitive. This shall be handed in the same way as for an association indication, except that for a secured rejoin the update device and key transport step.

Full network operation shall not be permitted until the verification steps described below have been carried out.

Measures shall be taken by a newly (re-)joined node and by its new parent to verify that it is really allowed to be on this network. Two cases are envisioned:

- One or the other is not implemented according to this specification, and should not have joined. The measures described here allow both sides to revoke the join in this case.

- One or the other device is a compromised/hacked device. In the case that security is enabled, the measures in sub-clause 4.6.3.6 are additionally applied so that an unauthorized join is revoked.

This verification is carried out using existing commands. sub-clause 2.5.5.5.4.3 below describes the transmission of a `Device_annce` command to the new parent. The new parent shall check that this or some other message is correctly formed and contains the addressing fields corresponding to the orphaned device. If security is enabled, then this command shall be secured with the network key, and the new parent shall verify that all security processing is carried out correctly. If all these checks succeed then the orphaned device shall become joined to the network. Otherwise, it shall not become joined to the network at this time. As normal, messages sent from a device not joined to the network shall not be forwarded across the network, and commands shall not be carried out. Accordingly, the orphaned device shall only become joined to the network once it receives at least one correctly formed ZigBee message from the new parent. If security is enabled, this message must be secured with the network key and all security processing must be carried out correctly. If messages cannot be exchanged in protocol, then the orphaned device shall not become joined to the network at this time.

2.5.5.5.4.3 Description of Operations for Informing the Rest of the Network

If the ZigBee End Device rejoins a new parent using the orphaning of rejoin process it shall complete the address conflict process in sub-clause 3.6.1.9. Upon receiving the `Device_annce`, all devices shall check their internal tables holding 64-bit IEEE addresses for devices within the PAN for a match with the address supplied in the `Device_annce` message. If a match is detected, the device shall update the `nwkAddressMap` attribute of the NIB corresponding to the matched 64-bit IEEE address to reflect the updated 16-bit NWK address contained in the `Device_annce`. All devices shall use the NLME-SET and NLME-GET primitives to update the `nwkNeighborTable` in the NWK NIB. The previous parent of this ZED shall remove the ZED as one of its children by changing the Relationship field of the `nwkNeighborTable` to 0x04, “previous child.” Note that any unicast message sent to an address with this status shall result in an NLME-NWK-STATUS.indication primitive with status code of “Target Device Unavailable”, (see sub-clause 3.2.2.30). If `nwkUseTreeRouting` is TRUE, address conflict detection is not provided and parent devices are not permitted, following intra-PAN portability, to remove devices or any other operation that reissue a short address for use by a child with a different IEEE address. Alternatively, if `nwkUseTreeRouting` is FALSE, address conflict detection is provided, however, devices will generally keep their existing NWK addresses during the intra-PAN portability procedure. Also, if the NWK address has changed during the intra-PAN portability procedure, the ZDO shall arrange that any IEEE address to short address mappings which have become known to applications running on this

device be updated. This behavior is mandatory, but the mechanism by which it is achieved is outside the scope of this specification.

2.5.5.5.5 ZigBee End Device

2.5.5.5.5.1 Initialization

The implementation shall set the startup-related IB attributes shown in Table 2.140 to values that reflect the desired startup behavior for the device. In particular, the *apsDesignatedCoordinator* attribute of the IB shall be set to FALSE.

If supported, provision shall be made to supply configuration elements for the Complex Descriptor, User Descriptor, the maximum number of bind entries, and the master key. These elements shall be embodied in :Config_Complex_Descriptor, :Config_User_Descriptor, :Config_Max_Bind, and :Config_Master_Key. If the device application set the NLME-JOIN RxOnWhenIdle parameter to FALSE, the end device shall utilize the procedure described in sub-clause 2.5.2.1 to discover a Primary Discovery Cache device, register with it, and to successfully upload its device and service discovery information. To facilitate the process of uploading discovery information to the Primary Discovery Cache device, the local device may temporarily increase its polling rate with its parent. Prior to registering with any Primary Discovery Cache device, the end device shall utilize the Find Node Cache request to ensure it has not previously registered with any other Primary Discovery Cache device. If a server response indicates the end device has a previous registration, the end device shall update its discovery cache information on that Primary Discovery Cache device or shall remove its discovery cache information from that previous registration and create a new registration.

To start as a ZigBee end device, the device application shall execute the startup procedure described in sub-clause 2.5.5.5.6.2 with startup parameters set as described above. This should have the effect of executing either the procedure for network rejoin described in sub-clause 3.6.1.4.2 or else the full procedure for network join through MAC association described in sub-clause 3.6.1.4.1. The NLME-NETWORK-DISCOVERY.request procedure shall be implemented :Config_NWK_Scan_Attempts, each separated in time by :Config_NWK_Time_btwn_Scans. The purpose of repeating the NLME-NETWORK-DISCOVERY.request is to provide a more accurate neighbor list and associated link quality indications to the NWK layer. Specification of the algorithm for selection of the PAN shall be left to the profile description and may include use of the Extended PAN ID, operational mode of the network, identity of the ZigBee Router or Coordinator identified on the PAN, depth of the ZigBee Router on the PAN from the ZigBee Coordinator for the PAN, capacity of the ZigBee Router or Coordinator, the routing cost, or the Protocol Version Number (these parameters are supplied by the NLME-NETWORK-DISCOVERY.confirm and the beacon payload).

The ZigBee end device may join networks employing the current protocol version number or may join networks employing a previous protocol version number, under application control, if backward compatibility is supported in the device. A single ZigBee PAN shall consist of devices employing only a single protocol version number (networks with devices employing different protocol version numbers and frame formats within the same PAN are not permitted). An optional configuration attribute, `:Config_NWK_alt_protocol_version`, provides the protocol version numbers which the device may choose to employ other than the current protocol version number. Once the ZigBee end device chooses a PAN and a specific protocol version number, it shall employ that protocol version number as its *nwkProtocolVersion*. Additionally, the ZigBee end device shall then adhere to all frame formats and processing rules supplied by the version of the ZigBee Specification employing that protocol version number.

If the device application sets the NLME-JOIN `RxOnWhenIdle` parameter to `FALSE`, the `:Config_NWK_indirectPollRate` shall be used to determine the polling rate for indirect message requests. The `:Config_NWK_indirectPollRate` shall be set according to the value established by the application profile(s) supported on the device. Once polling for indirect message requests is initiated, if communications failure with the parent is detected determined by failure of indirect message requests `:Config_Parent_Link_Threshold_Retry` consecutive attempts, the device application shall employ the network rejoin procedure.

Once the End Device has successfully joined a network, the device shall issue a `Device_annce` providing its 64-bit IEEE address and 16-bit NWK address.

Provision shall be made to ensure APS primitive calls from the end applications over EP 1 through EP 254 return appropriate error status values prior to completion of the Initialization state by ZigBee Device Objects and transition to the normal operating state.

If the network has security enabled, the device shall wait to be authenticated by the Trust Center and for successful acquisition of the NWK key to start functioning as an end device in the network. See sub-clause 4.6.2 for details on Trust Center operations.

2.5.5.5.2 Normal Operating State

If the device application set the NLME-JOIN `RxOnWhenIdle` parameter to `FALSE`, the `:Config_NWK_indirectPollRate` shall be used to poll the parent for indirect transmissions while in the normal operating state. While a fragmented message is being received, the device may temporarily increase its polling rate, and shall ensure that it polls its parent at least once every `macTransactionPersistenceTime` seconds.

The ZigBee end device shall respond to any device discovery or service discovery operations requested of its own device using the attributes described in sub-clause 2.5.4.

If security is enabled operating in commercial mode, the ZigBee end device shall support the :Config_Master_Key and shall employ the Master Key in key establishment procedures for Link Keys. Upon presentation of a remote destination address requiring secure communications, the ZigBee end device shall support APSME-ESTABLISH-KEY.request to establish a link key with the remote device, and support APSME-ESTABLISH-KEY.indication to present the request to the destination, and shall support APSME-ESTABLISH-KEY.confirm and APSME-ESTABLISH-KEY.response to complete the key establishment of the Link Key. The ZigBee end device shall provide the ability to store Link Keys for known destinations requiring secure communications and shall manage key storage of Link Keys. The ZigBee end device shall support APSME-TRANSPORT-KEY.indication to receive keys from the Trust Center.

If security is enabled operating in commercial mode, the ZigBee end device shall request the Trust Center to update its NWK key via the APSME-REQUEST-KEY.request.

The ZigBee End Device shall process Device_annce messages from other ZigBee devices. Upon receipt of a Device_annce where *nwkUseTreeRouting* is TRUE, the ZigBee End Device shall check all internal tables holding 64-bit IEEE addresses for devices within the PAN for a match with the address supplied in the Device_annce message. If a match is detected, the ZigBee End Device shall update the *nwkAddressMap* of the NIB corresponding to the matched 64-bit IEEE address to reflect the updated 16-bit NWK address contained in the Device_annce.

The ZigBee End Device shall process the NLME-NWK-STATUS.indication sent from the NWK layer. If the error code equals to 0x09 (Parent Link Failure), the ZED will update its failure counter maintained in ZDO. If the value of the failure counter is smaller than the :Config_Parent_Link_Retry_Threshold attribute, the ZED may decide to issue further commands to attempt to communicate with the parent node, depending on the application of the ZED. If the value of the failure counter exceeds the :Config_Parent_Link_Retry_Threshold attribute, the ZED shall then prepare to start the rejoin process. Note that implementers may optionally use a more accurate time-windowed scheme to identify a link failure.

The rejoin process mirrors the MAC association process very closely, however, a device is permitted to rejoin a parent that is not accepting new associations. The ZDO may use the NLME-NETWORK-DISCOVERY.request primitive to detect potential alternative parents, and in order to optimize recovery latency and reliability, shall select an appropriate new parent based on the following information from that device's beacon:

- PAN ID
- EPID (Extended PAN ID)
- Channel
- Signal strength
- Whether the potential parent indicates that it is currently able to communicate with its Trust Center
- Whether this device has recently failed to join this parent, or this network

Once a potential parent has been selected, the ZDO shall issue an NLME-JOIN.request primitive with RejoinNetwork set to 0x02.

The start time of the rejoin process is determined by the time the last NLME-JOIN.request primitive was sent and by the attribute :Config_Rejoin_Interval. Only if the interval between the current and the previous NLME-JOIN.request sent time is longer than the :Config_Rejoin_Interval shall a new NLME-JOIN.request primitive be sent. The application may want to gradually increase the :Config_Rejoin_Interval if a certain number of retries have been done (or a certain period of time has passed) but none of them were successful. The :Config_Rejoin_Interval should not exceed the :Config_Max_Rejoin_Interval. Every time an NLME-JOIN.confirm has been successfully received, the ZDO shall reset its failure counter to zero and the :Config_Rejoin_Interval attribute to its initial value. The choice of the default initial value and the algorithm of increasing the rejoin interval shall be determined by the application, and is out of the scope of this document.

If the ZigBee End Device rejoins a new parent using the rejoin process, it shall complete the address conflict process in sub-clause 3.6.1.9.

The ZigBee end device may generate APSME-AUTHENTICATE.requests under application control from other application objects and may process and respond to APSME-AUTHENTICATE.indications from other devices. The ZigBee end device shall supply APSME-AUTHENTICATE.confirms to application objects whose requests have been processed.

2.5.5.5.6 Support for Commissioning Applications

ZigBee devices in the field will need commissioning, and it will be up to developers to provide applications that perform such commissioning. There is a risk that applications from different vendors will work differently, thereby diminishing the ability of ZigBee devices from different vendors to operate seamlessly on the same network. As a partial solution to this problem, this sub-clause lists a common set of configuration attributes for ZigBee devices and outlines a common procedure for devices to use at start-up time. The other critical component of the solution is a common set of commissioning protocols and procedures, which are outside the scope of this document.

2.5.5.5.6.1 Configuration Attributes

The startup procedure outlined in sub-clause 2.5.5.5.6.2 is designed in such a way that, by using it consistently, devices can go through all the stages of commissioning up to being joined to the proper ZigBee network and able to send and receive application data traffic. Later-stage commissioning, including the commissioning of bindings and group membership is discussed briefly in sub-clause 2.5.5.5.6.3 below. The procedure makes use of the system attributes listed in Table 2.140.

Table 2.140 Startup Attributes

Name	Reference	Comment
<i>nwkExtendedPANID</i>	Table 3.43	This is the extended PANID of the network to which the device is joined. If it has a value of 0x0000000000000000, then the device is not connected to a network.
<i>apsDesignatedCoordinator</i>	Table 2.24	This boolean flag indicates whether the device should assume on startup that it must become a ZigBee coordinator.
<i>apsChannelMask</i>	Table 2.24	This is the mask containing allowable channels on which the device may attempt to form or join a network at startup time.
<i>apsUseExtendedPANID</i>	Table 2.24	The 64-bit identifier of the network to join or form.
<i>apsUseInsecureJoin</i>	Table 2.24	A boolean flag, which defaults to TRUE and indicates whether it is OK to use insecure join on startup.

2.5.5.5.6.2 Startup Procedure

The startup procedure uses the attributes listed in sub-clause 2.5.5.5.6.1 to perform a controlled startup of the ZigBee networking facilities of a device. The procedure should be run whenever the device restarts, but may also be run under application control at the discretion of the developer.

When a device starts up, it should check the value of *nwkExtendedPANID*. If *nwkExtendedPANID* has a non-zero value, then the device should assume it has all the network parameters required to operate on a network. Note that the device should assume the channel identifier present in its current network parameters but may need to scan over the ChannelMask if the *nwkExtendedPANID* is not found. In order for this to work effectively across power failures and processor resets, *nwkExtendedPANID* must be placed in non-volatile storage.

If the device finds it is not connected to a network, then it should check the value of *apsDesignatedCoordinator*. If this attribute has a value of TRUE, then the device should follow the procedures for starting a network outlined in sub-

clause 3.6.1.4.1 and should use the value of *apsChannelMask* for the ScanChannels parameter of the NLME-NETWORK-FORMATION.request primitive, and set *nwkExtendedPANID* to the value given in *apsUseExtendedPANID* if *apsUseExtendedPANID* has a non-zero value.

If the device is not the designated coordinator and *apsUseExtendedPANID* has a non-zero value, the device should attempt to rejoin the network specified in *apsUseExtendedPANID*. To do this, it should use NLME-JOIN.request with the ExtendedPANID parameter equal to the value of *apsUseExtendedPANID*, the ScanChannels parameter of the primitive equal to the value of the *apsChannelMask* configuration attribute. The RejoinNetwork parameter of the NLME-JOIN.request primitive should have a value of 0x02 indicating rejoin.

If the network rejoin attempt fails, and the value of the *apsUseInsecureJoin* attribute of the AIB has a value of TRUE, then the device should follow the procedure outlined in sub-clause 3.6.1.4.1 for joining a network, using *apsChannelMask* any place that a ScanChannels mask is called for. If *apsUseExtendedPANID* has a non-zero value, then the device should join only the specified network and the procedure should fail if that network is found to be inaccessible. If *apsUseExtendedPANID* is equal to 0x0000000000000000, then the device should join the best available network.

2.5.5.5.6.3 Further Commissioning

Once a device is on a network and capable of communicating with other devices on the network in a secure manner, other commissioning becomes possible. Other items that should be subject to commissioning are shown in Table 2.141.

Table 2.141 Additional Commissioning Attributes

Name	Reference	Comment
<i>apsBindingTable</i>	Table 2.24	The binding table for this device. Binding provides a separation of concerns in the sense that applications may operate without having to manage recipient address information for the frames they emit. This information can be input at commissioning time without the main application on the device even being aware of it.
<i>nwkGroupIDTable</i>	Table 3.43	Commissioning applications should be able to manage group membership of a device and its endpoints by accessing this table.
<i>nwkSecurityMaterialSet</i>	Table 4.2	This set contains the network keying material, which should be accessible to commissioning applications.

Table 2.141 Additional Commissioning Attributes

Name	Reference	Comment
<i>apsDeviceKeyPairSet</i>	Table 4.38	Contained in the set of key pairs for a device is the Trust Center master key, which should be accessible to commissioning applications.
<i>apsTrustCenterAddress</i>	Table 4.38	The IEEE address of the Trust Center.
<i>nwkNetworkAddress</i>	Table 3.44	Commissioning applications may set the network short address of devices as long as address conflicts that may arise as a result are subject to address conflict resolution as described in sub-clause 3.6.1.9.

2.5.5.6 Device and Service Discovery

The Device and Service Discovery function supports:

- Device Discovery
- Service Discovery

Device Management performs the above functions with the ZigBee Device Profile (see clause 2.4).

2.5.5.6.1 Optional and Mandatory Attributes Within Device and Service Discovery

All of the request attributes within the Device and Service Discovery Object are optional for all ZigBee logical device types. The responses listed in Table 2.142 as mandatory are mandatory for all ZigBee logical device types, and the responses listed as optional are optional for all ZigBee logical device types. See clause 2.4 for a description of any of these attributes.

Table 2.142 Device and Service Discovery Attributes

Attribute	M/O	Type
NWK_addr_req	O	Public
NWK_addr_rsp	M	Public
IEEE_addr_req	O	Public
IEEE_addr_rsp	M	Public
Node_Desc_req	O	Public
Node_Desc_rsp	M	Public
Power_Desc_req	O	Public
Power_Desc_rsp	M	Public

Table 2.142 Device and Service Discovery Attributes (Continued)

Attribute	M/O	Type
Simple_Desc_req	O	Public
Simple_Desc_rsp	M	Public
Active_EP_req	O	Public
Active_EP_rsp	M	Public
Match_Desc_req	O	Public
Match_Desc_rsp	M	Public
Complex_Desc_req	O	Public
Complex_Desc_rsp	O	Public
User_Desc_req	O	Public
User_Desc_rsp	O	Public
Device_annce	M	Public
User_Desc_set	O	Public
User_Desc_conf	O	Public
System_Server_Discovery_req	O	Public
System_Server_Discovery_rsp	O	Public
Discovery_Cache_req	O	Public
Discovery_Cache_rsp	O	Public
Discovery_store_req	O	Public
Discovery_store_rsp	O	Public
Node_Desc_store_req	O	Public
Node_Desc_store_rsp	O	Public
Power_Desc_store_req	O	Public
Power_Desc_store_rsp	O	Public
Active_EP_store_req	O	Public
Active_EP_store_rsp	O	Public
Simple_Desc_store_req	O	Public
Simple_Desc_store_rsp	O	Public
Remove_node_cache_req	O	Public

Table 2.142 Device and Service Discovery Attributes (Continued)

Attribute	M/O	Type
Remove_node_cache_rsp	O	Public
Find_node_cache_req	O	Public
Find_node_cache_rsp	O	Public

2.5.5.7 Security Manager

The security manager determines whether security is enabled or disabled and, if enabled, shall perform the following:

- Establish Key
- Transport Key
- Authentication

2.5.5.7.1 Optional and Mandatory Attributes Within Security Manager

The Security Manager itself is an optional object for all ZigBee Device Types. If the Security Manager is present, all requests and responses are mandatory for all ZigBee device types. If the Security Manager is not present, none of the attributes in the Security Manager are present for any ZigBee logical device type. See clause 2.4 for a description of any of the primitives listed in Table 2.143.

Table 2.143 Security Manager Attributes

Attribute	M/O	Type
APSME-ESTABLISH-KEY.request	O	Public
APSME-ESTABLISH-KEY.response	O	Public
APSME-ESTABLISH-KEY.indication	O	Public
APSME-ESTABLISH-KEY.confirm	O	Public
APSME-TRANSPORT-KEY.request	O	Public
APSME-TRANSPORT-KEY.indication	O	Public
APSME-UPDATE-DEVICE.request	O	Public
APSME-UPDATE-DEVICE.indication	O	Public
APSME-REMOVE-DEVICE.request	O	Public
APSME-REMOVE-DEVICE.indication	O	Public
APSME-REQUEST-KEY.request	O	Public
APSME-REQUEST-KEY.indication	O	Public
APSME-SWITCH-KEY.request	O	Public

Table 2.143 Security Manager Attributes (Continued)

APSME-SWITCH-KEY.indication	O	Public
APSME-AUTHENTICATE.request	O	Private
APSME-AUTHENTICATE.indication	O	Private
APSME-AUTHENTICATE.confirm	O	Private

2.5.5.8 Binding Manager

The Binding Management function supports:

- End Device Binding
- Bind and Unbind

Binding Management performs the above functions with ZigBee Device Profile commands plus APSME-SAP primitives to commit/remove binding table entries once the indication arrives on the ZigBee coordinator, router, or end device supporting the binding table.

2.5.5.8.1 Optional and Mandatory Attributes Within Binding Manager

The Binding Manager is an optional object for all ZigBee Device Types.

If the Binding Manager is present, all requests are optional for all ZigBee logical device types. Responses shall be supported on devices which implement a binding table cache, and on devices which correspond to the source address for the binding table entries held on those devices.

If the Binding Manager is not present, all requests and all responses for all ZigBee logical device types shall not be supported. Table 2.144 summarizes Binding Manager attributes.

Table 2.144 Binding Manager Attributes

Attribute	M/O	Type
End_Device_Bind_req	O	Public
End_Device_Bind_rsp	O	Public
Bind_req	O	Public
Bind_rsp	O	Public
Unbind_req	O	Public
Unbind_rsp	O	Public
Bind_Register_req	O	Public
Bind_Register_rsp	O	Public
Replace_Device_req	O	Public

Table 2.144 Binding Manager Attributes (Continued)

Attribute	M/O	Type
Replace_Device_rsp	O	Public
Store_Bkup_Bind_Entry_req	O	Public
Store_Bkup_Bind_Entry_rsp	O	Public
Remove_Bkup_Bind_req	O	Public
Remove_Bkup_Bind_rsp	O	Public
Backup_Bind_Table_req	O	Public
Backup_Bind_Table_rsp	O	Public
Recover_Bind_Table_req	O	Public
Recover_Bind_Table_rsp	O	Public
Backup_Source_Bind_req	O	Public
Backup_Source_Bind_rsp	O	Public
Recover_Source_Bind_req	O	Public
Recover_Source_Bind_rsp	O	Public
APSME-BIND.request	O	Private
APSME-BIND.confirm	O	Private
APSME-UNBIND.request	O	Private
APSME-UNBIND.confirm	O	Private

2.5.5.9 Network Manager

The Network Management function supports:

- Network Discovery
- Network Formation
- Permit/Disable Associations
- Association and Disassociation
- Route Discovery
- Network Reset
- Radio Receiver State Enable/Disable
- Get and Set of Network Management Information Block Data
- Detecting and reporting interference

- Receive network interference reports and change network channels if the particular node is identified as the network manager for the overall PAN

Network Management performs the above functions with NLME-SAP primitives (see Chapter 3).

2.5.5.9.1 Optional and Mandatory Attributes Within Network Manager

The Network Manager is a mandatory object for all ZigBee Device Types.

The Network Discovery, Get, and Set attributes (both requests and confirms) are mandatory for all ZigBee logical device types.

If the ZigBee logical device type is ZigBee Coordinator, the NWK Formation request and confirm, the NWK Leave request, NWK Leave indication, NWK Leave confirm, NWK Join indication, NWK Permit Joining request, and NWK Permit Joining confirm shall be supported. The NWK Direct Join request, NWK Direct Join confirm, NWK Route Discovery request, and NWK Route Discovery confirm may be supported. The NWK Join request and the NWK Join confirm shall not be supported.

If the ZigBee logical device type is ZigBee Router, the NWK Formation request and confirm shall not be supported. Additionally, the NWK Start Router request, NWK Start Router confirm, NWK Join request, NWK Join confirm, NWK Join indication, NWK Leave request, NWK Leave confirm, NWK Leave indication, NWK Permit Joining request, and NWK Permit Joining confirm shall be supported. The NWK Direct Join request, NWK Direct Join confirm, NWK Route Discovery request, and NWK Route Discovery confirm may be supported.

If the ZigBee logical device type is ZigBee End Device, the NWK Formation request and confirm plus the NWK Start Router request and confirm shall not be supported. Additionally, the NWK Join indication and NWK Permit Joining request shall not be supported. The NWK Join request, NWK Join confirm, NWK Leave request, NWK Leave indication, NWK Leave confirm shall be supported.

For all ZigBee logical devices types, the NWK Sync request, indication and confirm plus NWK reset request and confirm plus NWK route discovery request and confirm shall be optional. Table 2.145 summarizes Network Manager Attributes. See Chapter 3 for a description of any of the primitives listed in Table 2.145.

For all ZigBee logical device types, reception of the NWK Network Status indication shall be supported, but no action is required in this version of the specification.

Table 2.145 Network Manager Attributes

Attribute	M/O	Type
NLME-GET.request	M	Private
NLME-GET.confirm	M	Private
NLME-SET.request	M	Private
NLME-SET.confirm	M	Private
NLME-NETWORK-DISCOVERY.request	M	Public
NLME-NETWORK-DISCOVERY.confirm	M	Public
NLME-NETWORK-FORMATION.request	O	Private
NLME-NETWORK-FORMATION.confirm	O	Private
NLME-START-ROUTER.request	O	Private
NLME-START-ROUTER.confirm	O	Private
NLME-JOIN.request	O	Private
NLME-JOIN.confirm	O	Private
NLME_JOIN.indication	O	Private
NLME-PERMIT-JOINING	O	Public
NLME-PERMIT-JOINING.confirm	O	Public
NLME-DIRECT-JOIN.request	O	Public
NLME-DIRECT-JOIN.confirm	O	Public
NLME_LEAVE.request	M	Public
NLME-LEAVE.confirm	M	Public
NLME_LEAVE.indication	M	Public
NLME-RESET.request	O	Private
NLME-RESET.confirm	O	Private
NLME-SYNC.request	O	Public
NLME-SYNC.indication	O	Public
NLME-SYNC.confirm	O	Public
NLME-NWK-STATUS.indication	M	Private
NLME-ROUTE-DISCOVERY.request	O	Public

Table 2.145 Network Manager Attributes (Continued)

Attribute	M/O	Type
NLME-ROUTE-DISCOVERY.confirm	O	Private
NLME-ED-SCAN.request	O	Private
NLME-ED-SCAN.confirm	O	Private
NLME-START-BACKOFF.request	O	Private

A single device in the network can become the Network Channel Manager. The operation of the network channel manager is described in Annex E. All other devices in the network are responsible for tracking message delivery failures and reporting interference in accordance with Annex E.

2.5.5.10 Node Manager

The Node Manager supports the ability to request and respond to management functions. These management functions only provide visibility to external devices regarding the operating state of the device receiving the request.

2.5.5.10.1 Optional and Mandatory Attributes Within Node Manager

The Node Manager is an optional object for all ZigBee Device Types. All request and response attributes within Node Manager are also optional if the Node Manager object is present. Table 2.146 summarizes Node Manager attributes. See clause 2.4 for a description of these attributes.

Table 2.146 Node Manager Attributes

Attribute	M/O	Type
Mgmt_NWK_Disc_req	O	Public
Mgmt_NWK_Disc_rsp	O	Public
Mgmt_Lqi_req	O	Public
Mgmt_Lqi_rsp	O	Public
Mgmt_Rtg_req	O	Public
Mgmt_Rtg_rsp	O	Public
Mgmt_Bind_req	O	Public
Mgmt_Bind_rsp	O	Public
Mgmt_Leave_req	O	Public
Mgmt_Leave_rsp	O	Public
Mgmt_Direct_Join_req	O	Public
Mgmt_Direct_Join_rsp	O	Public

Table 2.146 Node Manager Attributes (Continued)

Attribute	M/O	Type
Mgmt_Permit_Joining_req	O	Public
Mgmt_Permit_Joining_rsp	O	Public
Mgmt_Cache_req	O	Public
Mgmt_Cache_rsp	O	Public
Mgmt_NWK_Update_req	O	Private
Mgmt_NWK_Update_notify	O	Private

2.5.5.11 Group Manager

The Group Manager supports the ability to include application objects within groups or to remove application objects from groups. The group management functions operate only on application objects within the local device. Mechanisms to manage groups on other devices are beyond the scope of this document.

2.5.5.11.1 Optional and Mandatory Attributes Within Group Manager

The Group Manager is an optional object for all ZigBee Device Types. All request and response attributes within Group Manager are also optional if the Group Manager object is present. Table 2.147 summarizes Group Manager attributes. See clause 2.4 for a description of these attributes.

Table 2.147 Group Manager Attributes

Attribute	M/O	Type
APSME-ADD-GROUP.request	O	Public
APSME-ADD-GROUP.confirm	O	Public
APSME-REMOVE-GROUP.request	O	Public
APSME-REMOVE-GROUP.confirm	O	Public
APSME-REMOVE-ALL-GROUPS.request	O	Public
APSME-REMOVE-ALL-GROUPS.confirm	O	Public

2.5.6 Configuration Attributes

This attribute is used to represent the minimum mandatory and/or optional attributes used as configuration attributes for a device.

Table 2.148 Configuration Attributes

Attribute	M/O	Type
:Config_Node_Descriptor	M	Public
:Config_Power_Descriptor	M	Public
:Config_Simple_Descriptors	M	Public
:Config_NWK_Scan_Attempts	M	Private
:Config_NWK_Time_btwn_Scans	M	Private
:Config_Complex_Descriptor	O	Public
:Config_User_Descriptor	O	Public
:Config_Max_Bind	O	Private
:Config_Master_Key	O	Private
:Config_EndDev_Bind_Timeout	O	Private
:Config_Permit_Join_Duration	O	Public
:Config_NWK_Security_Level	O	Private
:Config_NWK_Secure_All_Frames	O	Private
:Config_NWK_Leave_removeChildren	O	Private
:Config_NWK_BroadcastDeliveryTime	O	Private
:Config_NWK_TransactionPersistenceTime	O	Private
:Config_NWK_indirectPollRate	O	Private
:Config_Max_Assoc	O	Private
:Config_NWK_Join_Direct_Addrs	O	Public
:Config_Parent_Link_Retry_Threshold	O	Public
:Config_Rejoin_Interval	O	Public
:Config_Max_Rejoin_Interval	O	Public

2.5.6.1 Configuration Attribute Definitions

Table 2.149 Configuration Attribute Definitions

Attribute	Description	When Updated
:Config_Node_Descriptor	Contents of the Node Descriptor for this device (see sub-clause 2.3.2.3).	The :Config_Node_Descriptor is either created when the application is first loaded or initialized with a commissioning tool prior to when the device begins operations in the network. It is used for service discovery to describe node features to external inquiring devices.
:Config_Power_Descriptor	Contents of the Power Descriptor for this device (see sub-clause 2.3.2.4).	The :Config_Power_Descriptor is either created when the application is first loaded or initialized with a commissioning tool prior to when the device begins operations in the network. It is used for service discovery to describe node power features to external inquiring devices.
:Config_Simple_Descriptors	Contents of the Simple Descriptor(s) for each active endpoint for this device (see sub-clause 2.3.2.5).	The :Config_Simple_Descriptors are created when the application is first loaded and are treated as “read-only.” The Simple Descriptor are used for service discovery to describe interfacing features to external inquiring devices.
:Config_NWK_Scan_Attempts	Integer value representing the number of scan attempts to make before the NWK layer decides which ZigBee coordinator or router to associate with (see sub-clause 2.5.5.5). This attribute has default value of 5 and valid values between 1 and 255.	The :Config_NWK_Scan_Attempts is employed within ZDO to call the NLME-NETWORK-DISCOVERY.request primitive the indicated number of times (for routers and end devices).

Table 2.149 Configuration Attribute Definitions (Continued)

Attribute	Description	When Updated
:Config_NWK_Time_btwn_Scans	Integer value representing the time duration (in OctetDurations) between each NWK discovery attempt described by :Config_NWK_Scan_Attempts (see sub-clause 2.5.5.5). This attribute has a default value of 0xc35 OctetDurations (100 milliseconds on 2.4GHz) and valid values between 1 and 0x1f3fe1 OctetDurations (65535 milliseconds on 2.4GHz). ^a	The :Config_NWK_Time_btwn_Scans is employed within ZDO to provide a time duration between the NLME-NETWORK-DISCOVERY.request attempts. ^b
:Config_Complex_Descriptor	Contents of the (optional) Complex Descriptor for this device (see sub-clause 2.3.2.6).	The :Config_Complex_Descriptor is either created when the application is first loaded or initialized with a commissioning tool prior to when the device begins operations in the network. It is used for service discovery to describe extended device features for external inquiring devices.
:Config_User_Descriptor	Contents of the (optional) User Descriptor for this device (see sub-clause 2.3.2.7).	The :Config_User_Descriptor is either created when the application is first loaded or initialized with a commissioning tool prior to when the device begins operations in the network. It is used for service discovery to provide a descriptive character string for this device to external inquiring devices.
:Config_Max_Bind	A constant which describes the maximum number of binding entries permitted.	The :Config_Max_Bind is a maximum number of supported Binding Table entries for this device.

Table 2.149 Configuration Attribute Definitions (Continued)

Attribute	Description	When Updated
:Config_Master_Key	Master Key used if security is enabled for this device (see Chapter 4).	The :Config_Master_Key is either present when the application is first loaded or initialized with a commissioning tool prior to when the device begins operations in the network. It is used for security operations on the device if security is supported and enabled.
:Config_EndDev_Bind_Timeout	Timeout value in seconds employed in End Device Binding (see sub-clause 2.4.3.2).	The :Config_EndDev_Bind_Timeout is employed only on ZigBee Coordinators and used to determine whether end device bind requests have been received within the timeout window.
:Config_Permit_Join_Duration	Permit Join Duration value set by the NLME-PERMIT-JOINING.request primitive (see Chapter 3).	The default value for :Config_Permit_Join_Duration is 0x00, however, this value can be established differently according to the needs of the profile.
:Config_NWK_Security_Level	Security level of the network (see Chapter 3).	This attribute is used only on the Trust Center and is used to set the level of security on the network.
:Config_NWK_Secure_All_Frames	If all network frames should be secured (see Chapter 3).	This attribute is used only on the Trust Center and is used to determine if network layer security shall be applied to all frames in the network.
:Config_NWK_Leave_remove Children	Sets the policy as to whether child devices are to be removed if the device is asked to leave the network via NLME-LEAVE (see Chapter 3).	The policy for setting this attribute is found in the Stack Profile employed.
:Config_NWK_BroadcastDeliveryTime	See Table 3.57.	The value for this configuration attribute is established in the Stack Profile.

Table 2.149 Configuration Attribute Definitions (Continued)

Attribute	Description	When Updated
:Config_NWK_TransactionPersistenceTime	See Table 3.44. This attribute is mandatory for the ZigBee coordinator and ZigBee routers and not used for ZigBee End Devices.	The value for this configuration attribute is established in the Stack Profile.
:Config_NWK_Alt_protocol_version	Sets the list of protocol version numbers, other than the current protocol version number, that the device may choose to employ in a PAN that it joins. This attribute is applicable only to ZigBee routers or end devices. The protocol version numbers in the list must refer to older versions of the ZigBee Specification.	:Config_NWK_Alt_protocol_version permits ZigBee routers and ZigBee end devices to join networks discovered that employ an earlier version of the ZigBee Specification; Since this attribute is optional, devices may also be created omitting this attribute which require only the current version of the ZigBee Specification; This attribute would be omitted in cases where certain features are required that are contained only in the current specification or where code size is limited in the device.
:Config_NWK_indirectPollRate	Sets the poll rate, in milliseconds, for the device to request indirect transmission messages from the parent.	The value for this configuration attribute is established by the application profile deployed on the device.
:Config_Max_Assoc	Sets the maximum allowed associations, either of routers, end devices, or both, to a parent router or coordinator.	The value for this configuration attribute is established by the stack profile in use on the device. Note that for some stack profiles, the maximum associations may have a dimension which provides for separate maximums for router associations and end device associations.

Table 2.149 Configuration Attribute Definitions (Continued)

Attribute	Description	When Updated
:Config_NWK_Join_Direct_Addrs	Consists of the following fields: DeviceAddress - 64-bit IEEE address for the device to be direct joined CapabilityInformation - Operating capabilities of the device to be direct joined MasterKey - If security is enabled, master key for use in the key-pair descriptor for this new device (see Table 4.39) See sub-clause 3.2.2.14 for details.	:Config_NWK_Join_Direct_Addrs permits the ZigBee Coordinator or Router to be pre-configured with a list of addresses to be direct joined.
:Config_Parent_Link_Retry_Threshold	Contents of the link retry threshold for parent link (see sub-clause 2.5.5.5.5.2).	The :Config_Parent_Link_Retry_Threshold is either created when the application is first loaded or initialized with a commissioning tool. It is used for the ZED to decide how many times it should retry to connect to the parent router before initiating the rejoin process.
:Config_Rejoin_Interval	Contents of the rejoin interval (see sub-clause 2.5.5.5.5.2).	The :Config_Rejoin_Interval is either created when the application is first loaded or initialized with a commissioning tool. It is used by the ZED to decide how often it should initiate the rejoin process.
:Config_MAX_Rejoin_Interval	Contents of the maximal rejoin interval (2.5.5.5.5.2).	The :Config_MAX_Rejoin_Interval is either created when the application is first loaded or initialized with a commissioning tool. It is used by the ZED to set the maximum value permitted for :Config_Rejoin_Interval during the rejoin procedure.

- a. ZigBee Document 12-0220-04
- b. ZigBee Document 12-0220-04

CHAPTER

3

NETWORK SPECIFICATION

3.1 General Description

3.1.1 Network (NWK) Layer Overview

The network layer is required to provide functionality to ensure correct operation of the IEEE 802.15.4-2003 MAC sub-layer and to provide a suitable service interface to the application layer. To interface with the application layer, the network layer conceptually includes two service entities that provide the necessary functionality. These service entities are the data service and the management service. The NWK layer data entity (NLDE) provides the data transmission service via its associated SAP, the NLDE-SAP, and the NWK layer management entity (NLME) provides the management service via its associated SAP, the NLME-SAP. The NLME utilizes the NLDE to achieve some of its management tasks and it also maintains a database of managed objects known as the network information base (NIB).

3.1.1.1 Network Layer Data Entity (NLDE)

The NLDE shall provide a data service to allow an application to transport application protocol data units (APDU) between two or more devices. The devices themselves must be located on the same network.

The NLDE will provide the following services:

- **Generation of the Network level PDU (NPDU):** The NLDE shall be capable of generating an NPDU from an application support sub-layer PDU through the addition of an appropriate protocol header.
- **Topology-specific routing:** The NLDE shall be able to transmit an NPDU to an appropriate device that is either the final destination of the communication or the next step toward the final destination in the communication chain.

- **Security:** The ability to ensure both the authenticity and confidentiality of a transmission.

3.1.1.2 Network Layer Management Entity (NLME)

The NLME shall provide a management service to allow an application to interact with the stack.

The NLME shall provide the following services:

- **Configuring a new device:** this is the ability to sufficiently configure the stack for operation as required. Configuration options include beginning an operation as a ZigBee coordinator or joining an existing network.
- **Starting a network:** this is the ability to establish a new network.
- **Joining, rejoining and leaving a network:** this is the ability to join, rejoin or leave a network as well as the ability of a ZigBee coordinator or ZigBee router to request that a device leave the network.
- **Addressing:** this is the ability of ZigBee coordinators and routers to assign addresses to devices joining the network.
- **Neighbor discovery:** this is the ability to discover, record, and report information pertaining to the one-hop neighbors of a device.
- **Route discovery:** this is the ability to discover and record paths through the network, whereby messages may be efficiently routed.
- **Reception control:** this is the ability for a device to control when the receiver is activated and for how long, enabling MAC sub-layer synchronization or direct reception.
- **Routing:** this is the ability to use different routing mechanisms such as unicast, broadcast, multicast or many to one to efficiently exchange data in the network.

3.2 Service Specification

Figure 3.1 depicts the components and interfaces of the NWK layer.

The NWK layer provides two services, accessed through two service access points (SAPs). These are the NWK data service, accessed through the NWK layer data entity SAP (NLDE-SAP), and the NWK management service, accessed through the NWK layer management entity SAP (NLME-SAP). These two services provide the interface between the application and the MAC sub-layer, via the MCPS-SAP and MLME-SAP interfaces (See [B1]). In addition to these external interfaces, there is also an implicit interface between the NLME and the NLDE that allows the NLME to use the NWK data service.

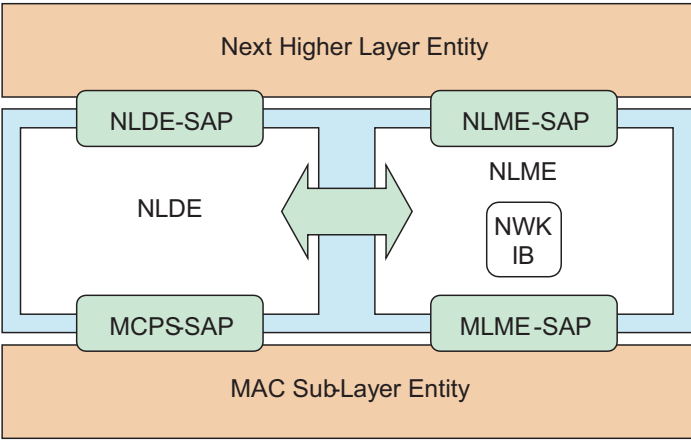


Figure 3.1 The NWK Layer Reference Model

3.2.1 NWK Data Service

The NWK layer data entity SAP (NLDE-SAP) supports the transport of application protocol data units (APDUs) between peer application entities. Table 3.1 lists the primitives supported by the NLDE-SAP and the sub-clauses in which these primitives are discussed.

Table 3.1 NLDE-SAP Primitives

NLDE-SAP Primitive	Request	Confirm	Indication
NLDE-DATA	3.2.1.1	3.2.1.2	3.2.1.3

3.2.1.1 NLDE-DATA.request

This primitive requests the transfer of a data PDU (NSDU) from the local APS sub-layer entity to a single or multiple peer APS sub-layer entities.

3.2.1.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLDE-DATA.request	{
	DstAddrMode,
	DstAddr,
	NsduLength,
	Nsdu,
	NsduHandle,
	Radius,
	NonmemberRadius,
	DiscoverRoute,
	SecurityEnable
	}

Table 3.2 specifies the parameters for the NLDE-DATA.request primitive.

Table 3.2 NLDE-DATA.request Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x01 or 0x02	The type of destination address supplied by the DstAddr parameter. This may have one of the following two values: 0x01=16-bit multicast group address 0x02=16-bit network address of a device or a 16-bit broadcast address
DstAddr	16-bit Address	0x0000-0xffff	Destination address.
NsduLength	Integer	$aMaxMACFrameSize - (nwkcMACFrameOverhead + nwkcMinHeaderOverhead)$	The number of octets comprising the NSDU to be transferred. This has been modified from the <i>aMaxMACFrameSize</i> limit specified in the IEEE 802.15.4 specification to take into account that the ZigBee network layer does not use the extended addressing modes. The effect of this is to free the unused portion of the header to be used for payload. See sub-clause D.4.
Nsdu	Set of Octets	-	The set of octets comprising the NSDU to be transferred.
NsduHandle	Integer	0x00 – 0xff	The handle associated with the NSDU to be transmitted by the NWK layer entity.

Table 3.2 NLDE-DATA.request Parameters (Continued)

Name	Type	Valid Range	Description
Radius	Unsigned Integer	0x00 – 0xff	The distance, in hops, that a frame will be allowed to travel through the network.
NonmemberRadius	Integer	0x00 – 0x07	The distance, in hops, that a multicast frame will be relayed by nodes not a member of the group. A value of 0x07 is treated as infinity.
DiscoverRoute	Integer	0x00 – 0x01	The DiscoverRoute parameter may be used to control route discovery operations for the transit of this frame (see sub-clause 3.6.3.5): 0x00 = suppress route discovery 0x01 = enable route discovery
SecurityEnable	Boolean	TRUE or FALSE	The SecurityEnable parameter may be used to enable NWK layer security processing for the current frame. If the <i>nwkSecurityLevel</i> attribute of the NIB has a value of 0, meaning no security, then this parameter will be ignored. Otherwise, a value of TRUE denotes that the security processing specified by the security level will be applied, and a value of FALSE denotes that no security processing will be applied.

3.2.1.1.2 When Generated

This primitive is generated by a local APS sub-layer entity whenever a data PDU (NSDU) is to be transferred to a peer APS sub-layer entity.

3.2.1.1.3 Effect on Receipt

If this primitive is received on a device that is not currently associated, the NWK layer will issue an NLDE-DATA.confirm primitive with a status of INVALID_REQUEST.

On receipt of this primitive, the NLDE first constructs an NPDU in order to transmit the supplied NSDU. If, during processing, the NLDE issues the NLDE-DATA.confirm primitive prior to transmission of the NSDU, all further processing is aborted. In constructing the new NPDU, the destination address field of the NWK header will be set to the value provided in the DstAddr parameter, and the source address field will have the value of the *macShortAddress* attribute in the MAC PIB. The discover route sub-field of the frame control field of the NWK header will be set to the value provided in the DiscoverRoute parameter. If the supplied Radius parameter does not have a value of zero, then the radius field of

the NWK header will be set to the value of the Radius parameter. If the Radius parameter has a value of zero, then the radius field of the NWK header will be set to twice the value of the *nwkMaxDepth* attribute of the NIB. The NWK layer will generate a sequence number for the frame as described in sub-clause 3.6.2.1. and the sequence number field of the NWK header of the frame will be set to this sequence number value. The multicast flag field of the NWK header will be set according to the value of the *DstAddrMode* parameter. If the *DstAddrMode* parameter has a value of 0x01, the NWK header will contain a multicast control field whose fields will be set as follows:

- The multicast mode field will be set to 0x01 if this node is a member of the group specified in the *DstAddr* parameter.
- Otherwise, the multicast mode field will be set to 0x00.
- The non-member radius and the max non-member radius fields will be set to the value of the *NonmemberRadius* parameter.

Once the NPDU is constructed, the NSDU is routed using the procedure described in sub-clause 3.6.3.3 if it is a unicast, sub-clause 3.6.5 if it is a broadcast, or sub-clause 3.6.6.2 if it is a multicast. When the routing procedure specifies that the NSDU is to be transmitted, this is accomplished by issuing the MCPS-DATA.request primitive with both the *SrcAddrMode* and *DstAddrMode* parameters set to 0x02, indicating the use of 16-bit network addresses. The *SrcPANId* and *DstPANId* parameters should be set to the current value of *macPANId* from the MAC PIB. The *SrcAddr* parameter will be set to the value of *macShortAddr* from the MAC PIB. The value of the *DstAddr* parameter is the next hop address determined by the routing procedure. If the message is a unicast, bit b0 of the *TxOptions* parameter should be set to 1 denoting that an acknowledgement is required. On receipt of the MCPS-DATA.confirm primitive on a unicast, the NLDE issues the NLDE-DATA.confirm primitive with a status equal to that received from the MAC sub-layer. Upon transmission of a MCPS-DATA.confirm primitive, in the case of a broadcast or multicast, the NLDE immediately issues the NLDE-DATA.confirm primitive with a status of success.

If the *nwkSecurityLevel* NIB attribute has a non-zero value and the *SecurityEnable* parameter has a value of TRUE, then NWK layer security processing will be applied to the frame before transmission as described in clause 4.3. Otherwise, no security processing will be performed at the NWK layer for this frame. If security processing is performed and it fails for any reason, then the frame is discarded and the NLDE issues the NLDE-DATA.confirm primitive with a Status parameter value equal to that returned by the security suite.

3.2.1.2 NLDE-DATA.confirm

This primitive reports the results of a request to transfer a data PDU (NSDU) from a local APS sub-layer entity to a single peer APS sub-layer entity.

3.2.1.2.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

```

NLDE-DATA.confirm      {
                        Status
                        NsduHandle,
                        TxTime
                        }
    
```

Table 3.3 specifies the parameters for the NLDE-DATA.confirm primitive.

Table 3.3 NLDE-DATA.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	INVALID_REQUEST, MAX_FRM_COUNTER, NO_KEY, BAD_CCM_OUTPUT, ROUTE_ERROR, BT_TABLE_FULL, FRAME_NOT_BUFFERED or any status values returned from security suite or the MCPS-DATA.confirm primitive (see [B1])	The status of the corresponding request.
NsduHandle	Integer	0x00 – 0xff	The handle associated with the NSDU being confirmed.
TxTime	Integer	Implementation specific	A time indication for the transmitted packet based on the local clock. The time should be based on the same point for each transmitted packet in a given implementation. This value is only provided if <i>nwkTimeStamp</i> is set to TRUE.

3.2.1.2.2 When Generated

This primitive is generated by the local NLDE in response to the reception of an NLDE-DATA.request primitive.

The Status field will reflect the status of the corresponding request, as described in sub-clause 3.2.1.1.3.

3.2.1.2.3 Effect on Receipt

On receipt of this primitive, the APS sub-layer of the initiating device is notified of the result of its request to transmit. If the transmission attempt was successful,

the Status parameter will be set to SUCCESS. Otherwise, the Status parameter will indicate the error.

3.2.1.3 NLDE-DATA.indication

This primitive indicates the transfer of a data PDU (NSDU) from the NWK layer to the local APS sub-layer entity.

3.2.1.3.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLDE-DATA.indication	{
	DstAddrMode,
	DstAddr,
	SrcAddr,
	NsduLength,
	Nsdu,
	LinkQuality
	RxTime
	SecurityUse
	}

Table 3.4 specifies the parameters for the NLDE-DATA.indication primitive.

Table 3.4 NLDE-DATA.indication Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x01 or 0x02	The type of destination address supplied by the DstAddr parameter. This may have one of the following two values: 0x01=16-bit multicast group address 0x02=16-bit network address of a device or a 16-bit broadcast address
DstAddr	16-bit Address	0x0000-0xffff	The destination address to which the NSDU was sent.
SrcAddr	16-bit Device address	Any valid device address except a broadcast address	The individual device address from which the NSDU originated.

Table 3.4 NLDE-DATA.indication Parameters (Continued)

NsduLength	Integer	$< aMaxMACFrameSize - (nwkcMACFrameOverhead + nwkcMinHeaderOverhead)$	The number of octets comprising the NSDU being indicated. This has been modified from the <i>aMaxMACFrameSize</i> limit specified in the IEEE 802.15.4 specification to take into account that the ZigBee network layer does not use the extended addressing modes. The effect of this is to free the unused portion of the header to be used for payload. See sub-clause D.4.
Nsdu	Set of octets	–	The set of octets comprising the NSDU being indicated.
LinkQuality	Integer	0x00 – 0xff	The link quality indication delivered by the MAC on receipt of this frame as a parameter of the MCPS-DATA.indication primitive (see [B1]).
RxTime	Integer	Implementation specific	A time indication for the received packet based on the local clock. The time should be based on the same point for each received packet on a given implementation. This value is only provided if <i>nwkTimeStamp</i> is set to TRUE.
SecurityUse	Boolean	TRUE or FALSE	An indication of whether the received data frame is using security. This value is set to TRUE if security was applied to the received frame or FALSE if the received frame was unsecured.

3.2.1.3.2 When Generated

This primitive is generated by the NLDE and issued to the APS sub-layer on receipt of an appropriately addressed data frame from the local MAC sub-layer entity.

3.2.1.3.3 Effect on Receipt

On receipt of this primitive, the APS sub-layer is notified of the arrival of data at the device.

3.2.2 NWK Management Service

The NWK layer management entity SAP (NLME-SAP) allows the transport of management commands between the next higher layer and the NLME. Table 3.5 lists the primitives supported by the NLME through the NLME-SAP interface and the sub-clauses containing details on each of these primitives.

Table 3.5 Summary of the Primitives Accessed Through the NLME-SAP

Name	Sub-Clause Number in This Specification			
	Request	Indication	Response	Confirm
NLME-NETWORK-DISCOVERY	3.2.2.1			3.2.2.2
NLME-NETWORK-FORMATION	3.2.2.3			3.2.2.4
NLME-PERMIT-JOINING	3.2.2.5			3.2.2.6
NLME-START-ROUTER	3.2.2.7			3.2.2.8
NLME-ED-SCAN	3.2.2.9			3.2.2.10
NLME-JOIN	3.2.2.11	3.2.2.12		3.2.2.13
NLME-DIRECT-JOIN	3.2.2.14			3.2.2.15
NLME-LEAVE	3.2.2.16	3.2.2.17		3.2.2.18
NLME-RESET	3.2.2.19			3.2.2.20
NLME-SYNC	3.2.2.22			3.2.2.24
NLME-SYNC-LOSS		3.2.2.23		
NLME-GET	3.2.2.26			3.2.2.27
NLME-SET	3.2.2.28			3.2.2.29
NLME-NWK-STATUS		3.2.2.30		
NLME-ROUTE-DISCOVERY	3.2.2.31			3.2.2.32

3.2.2.1 NLME-NETWORK-DISCOVERY.request

This primitive allows the next higher layer to request that the NWK layer discover networks currently operating within the POS.

3.2.2.1.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-NETWORK-DISCOVERY.request	{
	ScanChannels,
	ScanDuration
	}

Table 3.6 specifies the parameters for the NLME-NETWORK-DISCOVERY.request primitive.

Table 3.6 NLME-NETWORK-DISCOVERY.request Parameters

Name	Type	Valid Range	Description
ScanChannels	Bitmap	32-bit field	The five most significant bits (b27,..., b31) are reserved. The 27 least significant bits (b0, b1,... b26) indicate which channels are to be scanned (1 = scan, 0 = do not scan) for each of the 27 valid channels (see [B1]).
ScanDuration	Integer	0x00 – 0x0e	A value used to calculate the length of time to spend scanning each channel: The time spent scanning each channel is (<i>aBaseSuperframeDuration</i> * (2 ⁿ + 1)) symbols, where n is the value of the ScanDuration parameter. For more information on MAC sub-layer scanning (see [B1]).

3.2.2.1.2 When Generated

This primitive is generated by the next higher layer of a ZigBee device and issued to its NLME to request the discovery of networks operating within the device's personal operating space (POS).

3.2.2.1.3 Effect on Receipt

On receipt of this primitive, the NWK layer will attempt to discover networks operating within the device's POS by performing an active scan over the channels specified in the ScanChannels argument for the period specified in the ScanDuration parameter. The scan is performed by means of the MLME-SCAN.request primitive.

On receipt of the MLME-SCAN.confirm primitive, the NLME issues the NLME-NETWORK-DISCOVERY.confirm primitive containing the information about the discovered networks with a Status parameter value equal to that returned with the MLME-SCAN.confirm.

3.2.2.2 NLME-NETWORK-DISCOVERY.confirm

This primitive reports the results of a network discovery operation.

3.2.2.2.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-NETWORK-DISCOVERY.confirm	{ Status NetworkCount, NetworkDescriptor, }
--------------------------------	---

Table 3.7 describes the arguments of the NLME-NETWORK-DISCOVERY.confirm primitive.

Table 3.7 NLME-NETWORK-DISCOVERY.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	Any status value returned with the MLME-SCAN.confirm primitive.	See [B1].
NetworkCount	Integer	0x00 – 0xff	Gives the number of networks discovered by the search.
NetworkDescriptor	List of network descriptors	The list contains the number of elements given by the NetworkCount parameter	A list of descriptors, one for each of the networks discovered. Table 3.8 gives a detailed account of the contents of each item.

Table 3.8 gives a detailed account of the contents of a network descriptor from the NetworkDescriptor parameter.

Table 3.8 Network Descriptor Information Fields

Name	Type	Valid Range	Description
ExtendedPANId	Integer	0x0000000000000001 - 0xfffffffffffffffe	The 64-bit PAN identifier of the network.
LogicalChannel	Integer	Selected from the available logical channels supported by the PHY (see [B1]).	The current logical channel occupied by the network.
StackProfile	Integer	0x00 – 0x0f	A ZigBee stack profile identifier indicating the stack profile in use in the discovered network.
ZigBeeVersion	Integer	0x00 – 0x0f	The version of the ZigBee protocol in use in the discovered network.

Table 3.8 Network Descriptor Information Fields (Continued)

Name	Type	Valid Range	Description
BeaconOrder	Integer	0x00 – 0x0f	This specifies how often the MAC sub-layer beacon is to be transmitted by a given device on the network. For a discussion of MAC sub-layer beacon order see [B1].
SuperframeOrder	Integer	0x00 – 0x0f	For beacon-oriented networks, that is, beacon order < 15, this specifies the length of the active period of the superframe. For a discussion of MAC sub-layer superframe order see [B1].
PermitJoining	Boolean	TRUE or FALSE	A value of TRUE indicates that at least one ZigBee router on the network currently permits joining, <i>i.e.</i> its NWK has been issued an NLME-PERMIT-JOINING primitive and, the time limit if given, has not yet expired.
RouterCapacity	Boolean	TRUE or FALSE	This value is set to true if the device is capable of accepting join requests from router-capable devices and set to FALSE otherwise.
EndDeviceCapacity	Boolean	TRUE or FALSE	This value is set to true if the device is capable of accepting join requests from end devices and set to FALSE otherwise.

3.2.2.2.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer on completion of the discovery task initiated by an NLME-NETWORK-DISCOVERY.request primitive.

3.2.2.2.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of a network search.

3.2.2.3 NLME-NETWORK-FORMATION.request

This primitive allows the next higher layer to request that the device start a new ZigBee network with itself as the coordinator and subsequently make changes to its superframe configuration.

3.2.2.3.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-NETWORK-FORMATION.request	{
	ScanChannels,
	ScanDuration,
	BeaconOrder,
	SuperframeOrder,
	BatteryLifeExtension
	}

Table 3.9 specifies the parameters for the NLME-NETWORK-FORMATION.request primitive.

Table 3.9 NLME-NETWORK-FORMATION.request Parameters

Name	Type	Valid Range	Description
ScanChannels	Bitmap	32-bit field	The five most significant bits (b27,..., b31) are reserved. The 27 least significant bits (b0, b1,... b26) indicate which channels are to be scanned in preparation for starting a network (1=scan, 0=do not scan) for each of the 27 valid channels (see [B1]).
ScanDuration	Integer	0x00 – 0x0e	A value used to calculate the length of time to spend scanning each channel. The time spent scanning each channel is (<i>aBaseSuperframeDuration</i> * (2 ^{<i>n</i>} + 1)) symbols, where <i>n</i> is the value of the ScanDuration parameter (see [B1]).
BeaconOrder	Integer	0x00 – 0x0f	The beacon order of the network that the higher layers wish to form.
SuperframeOrder	Integer	0x00 – 0x0f	The superframe order of the network that the higher layers wish to form.
BatteryLifeExtension	Boolean	TRUE or FALSE	If this value is TRUE, the NLME will request that the ZigBee coordinator is started supporting battery life extension mode; If this value is FALSE, the NLME will request that the ZigBee coordinator is started without supporting battery life extension mode.

3.2.2.3.2 When Generated

This primitive is generated by the next higher layer of a ZigBee coordinator-capable device and issued to its NLME to request the initialization of itself as the ZigBee coordinator of a new network.

3.2.2.3.3 Effect on Receipt

On receipt of this primitive by a device that is not capable of being a ZigBee coordinator, the NLME issues the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to INVALID_REQUEST.

If the device is to be initialized as a ZigBee coordinator, the NLME requests that the MAC sub-layer first perform an energy detection scan and then an active scan on the specified set of channels. To do this, the NLME issues the MLME-SCAN.request primitive to the MAC sub-layer with the ScanType parameter set to indicate an energy detection scan and then issues the primitive again with the ScanType parameter set to indicate an active scan. After the completion of the active scan, on receipt of the MLME-SCAN.confirm primitive from the MAC sub-layer, the NLME selects a suitable channel. The NWK layer will pick a PAN identifier that does not conflict with that of any network known to be operating on the chosen channel. Once a suitable channel and PAN identifier are found, the NLME will choose 0x0000 as the 16-bit short MAC address and inform the MAC sub-layer. To do this, the NLME issues the MLME-SET.request primitive to the MAC sub-layer to set the MAC PIB attribute *macShortAddress*. If the NIB attribute *nwkExtendedPANId* is equal to 0x0000000000000000, this attribute will be initialized with the value of the MAC constant *macExtendedAddress*. If no suitable channel or PAN identifier can be found, the NLME issues the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to STARTUP_FAILURE.

If only a single channel is provided in the higher layer request, the NLME does not need to request an energy scan prior to starting the network. An active scan is still conducted to ensure a PAN identifier is selected that does not conflict with that of any network known to be operating.

Next, the NLME issues the MLME-START.request primitive to the MAC sub-layer. The PANCoordinator parameter of the MLME-START.request primitive is set to TRUE. The BeaconOrder, SuperframeOrder, and BatteryLifeExtension parameters will have the same values as those given to the NLME-NETWORK-FORMATION.request. The CoordRealignment parameter in the MLME-START.request primitive is set to FALSE if the primitive is issued to start a new PAN. The CoordRealignment parameter is set to TRUE if the primitive is issued to change any of the PAN configuration attributes on an exiting PAN. On receipt of the associated MLME-START.confirm primitive, the NLME issues the NLME-NETWORK-FORMATION.confirm primitive to the next higher layer with the status returned from the MLME-START.confirm primitive.

3.2.2.4 NLME-NETWORK-FORMATION.confirm

This primitive reports the results of the request to initialize a ZigBee coordinator in a network.

3.2.2.4.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-NETWORK-FORMATION.confirm	{
	Status
	}

Table 3.10 specifies the parameters for the NLME-NETWORK-FORMATION.confirm primitive.

Table 3.10 NLME-NETWORK-FORMATION.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	INVALID_REQUEST, STARTUP_FAILURE or any status value returned from the MLME-START.confirm primitive	The result of the attempt to initialize a ZigBee coordinator.

3.2.2.4.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer in response to an NLME-NETWORK-FORMATION.request primitive. This primitive returns a status value of INVALID_REQUEST, STARTUP_FAILURE or any status value returned from the MLME-START.confirm primitive. Conditions under which these values may be returned are described in sub-clause 3.2.2.3.3.

3.2.2.4.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to initialize the device as a ZigBee coordinator. If the NLME has been successful, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

3.2.2.5 NLME-PERMIT-JOINING.request

This primitive allows the next higher layer of a ZigBee coordinator or router to set its MAC sub-layer association permit flag for a fixed period when it may accept devices onto its network.

3.2.2.5.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

```

NLME-PERMIT-JOINING.request    {
                                PermitDuration
                                }

```

Table 3.11 specifies the parameters for the NLME-PERMIT-JOINING.request primitive.

Table 3.11 NLME-PERMIT-JOINING.request Parameters

Name	Type	Valid Range	Description
PermitDuration	Integer	0x00 – 0xff	The length of time in seconds during which the ZigBee coordinator or router will allow associations. The value 0x00 and 0xff indicate that permission is disabled or enabled, respectively, without a specified time limit.

3.2.2.5.2 When Generated

This primitive is generated by the next higher layer of a ZigBee coordinator or router and issued to its NLME whenever it would like to permit or prohibit the joining of the network by new devices.

3.2.2.5.3 Effect on Receipt

It is only permissible that the next higher layer of a ZigBee coordinator or router issue this primitive. On receipt of this primitive by the NWK layer of a ZigBee end device, the NLME-PERMIT-JOINING.confirm primitive returns a status of INVALID_REQUEST.

On receipt of this primitive with the PermitDuration parameter set to 0x00, the NLME sets the MAC PIB attribute, *macAssociationPermit*, to FALSE by issuing the MLME-SET.request primitive to the MAC sub-layer. Once the MLME-SET.confirm primitive is received, the NLME issues the NLME-PERMIT-JOINING.confirm primitive with a status equal to that received from the MAC sub-layer.

On receipt of this primitive with the PermitDuration parameter set to 0xff, the NLME sets the MAC PIB attribute, *macAssociationPermit*, to TRUE by issuing the MLME-SET.request primitive to the MAC sub-layer. Once the MLME-SET.confirm primitive is received, the NLME issues the NLME-PERMIT-JOINING.confirm primitive with a status equal to that received from the MAC sub-layer.

On receipt of this primitive with the PermitDuration parameter set to any value other than 0x00 or 0xff, the NLME sets the MAC PIB attribute, *macAssociationPermit*, to TRUE as described above. Following the receipt of the MLME-SET.confirm primitive, the NLME starts a timer to expire after PermitDuration seconds. Once the timer is set, the NLME issues the NLME-PERMIT-JOINING.confirm primitive with a status equal to that received by the MAC sub-layer. On expiration of the timer, the NLME sets *macAssociationPermit* to FALSE by issuing the MLME-SET.request primitive.

Every NLME-PERMIT-JOINING.request primitive issued by the next higher layer supersedes all previous requests.

3.2.2.6 NLME-PERMIT-JOINING.confirm

This primitive allows the next higher layer of a ZigBee coordinator or router to be notified of the results of its request to permit the acceptance of devices onto the network.

3.2.2.6.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-PERMIT-JOINING.confirm	{
	Status
	}

Table 3.12 specifies the parameters for the NLME-PERMIT-JOINING.confirm primitive.

Table 3.12 NLME-PERMIT-JOINING.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	INVALID_REQUEST or any status returned from the MLME-SET.confirm primitive (see [B1]).	The status of the corresponding request

3.2.2.6.2 When Generated

This primitive is generated by the initiating NLME of a ZigBee coordinator or router and issued to its next higher layer in response to an NLME-PERMIT-JOINING.request. The Status parameter either indicates the status received from the MAC sub-layer or an error code of INVALID_REQUEST. The reasons for these status values are described in sub-clause 3.2.2.5.

3.2.2.6.3 Effect on Receipt

On receipt of this primitive, the next higher layer of the initiating device is notified of the results of its request to permit devices to join the network.

3.2.2.7 NLME-START-ROUTER.request

This primitive allows the next higher layer of a ZigBee router to initiate the activities expected of a ZigBee router including the routing of data frames, route discovery, and the accepting of requests to join the network from other devices.

3.2.2.7.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-START-ROUTER.request	{
	BeaconOrder,
	SuperframeOrder,
	BatteryLifeExtension
	}

Table 3.13 specifies the parameters for NLME-START-ROUTER.request.

Table 3.13 NLME-START-ROUTER.request Parameters

Name	Type	Valid Range	Description
BeaconOrder	Integer	0x00 – 0x0f	The beacon order of the network that the higher layers wish to form.
SuperframeOrder	Integer	0x00 – 0x0f	The superframe order of the network that the higher layers wish to form.
BatteryLifeExtension	Boolean	TRUE or FALSE	If this value is TRUE, the NLME will request that the ZigBee router is started supporting battery life extension mode; If this value is FALSE, the NLME will request that the ZigBee router is started without supporting battery life extension mode.

3.2.2.7.2 When Generated

This primitive is generated by the next higher layer of a new device and issued to its NLME to request the initialization of itself as a ZigBee router.

3.2.2.7.3 Effect on Receipt

On receipt of this primitive by a device that is not already joined to a ZigBee network as a router, the NLME issues the NLME-START-ROUTER.confirm primitive with the Status parameter set to INVALID_REQUEST.

On receipt of this primitive by the NLME of a device that is joined to a ZigBee network as a router, the NLME issues the MLME-START.request primitive to the MAC sub-layer. The BeaconOrder, SuperframeOrder, and BatteryLifeExtension parameters of the MLME-START.request primitive will have the values given by the corresponding parameters of the NLME-START-ROUTER.request. The

CoordRealignment parameter in the MLME-START.request primitive is set to FALSE if the primitive is issued to start as a router for the first time. The CoordRealignment parameter is set to TRUE thereafter if the primitive is issued to change any of the PAN configuration attributes.

On receipt of the associated MLME-START.confirm primitive, the NLME issues the NLME-START-ROUTER.confirm primitive to the next higher layer with the status returned from the MLME-START.confirm primitive. If, and only if, the status returned from the MLME-START.confirm primitive is SUCCESS, the device may then begin to engage in the activities expected of a ZigBee router including the routing of data frames, route discovery, and the accepting of requests to join the network from other devices. Otherwise, the device is expressly forbidden to engage in these activities.

3.2.2.8 NLME-START-ROUTER.confirm

This primitive reports the results of the request to initialize a ZigBee router.

3.2.2.8.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-START-ROUTER.confirm	{
	Status
	}

Table 3.14 specifies the parameters for NLME-START-ROUTER.confirm.

Table 3.14 NLME-START-ROUTER.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	INVALID_REQUEST or any status value returned from the MLME-START.confirm primitive.	The result of the attempt to initialize a ZigBee router.

3.2.2.8.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer in response to an NLME-START-ROUTER.request primitive. This primitive returns a status value of INVALID_REQUEST or any status value returned from the MLME-START.confirm primitive. Conditions under which these values may be returned are described in sub-clause 3.2.2.7.3.

3.2.2.8.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to initialize a ZigBee router. If the NLME has been successful, the Status

parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

3.2.2.9 NLME-ED-SCAN.request

This primitive allows the next higher layer to request an energy scan to evaluate channels in the local area.

3.2.2.9.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-ED-SCAN.request	{
	ScanChannels,
	ScanDuration,
	}

Table 3.15 specifies the parameters for the service primitive.

Table 3.15 NLME-ED-SCAN.request Parameters

Name	Type	Valid Range	Description
ScanChannels	Bitmap	32-bit field	The five most significant bits (b27,..., b31) are reserved. The 27 least significant bits (b0, b1,... b26) indicate which channels are to be scanned (1=scan, 0=do not scan) for each of the 27 valid channels (see [B1]).
ScanDuration	Integer	0x00-0x0e	A value used to calculate the length of time to spend scanning each channel. The time spent scanning each channel is ($aBaseSuperframeDuration * (2^n + 1)$) symbols, where n is the value of the ScanDuration parameter [B1].

3.2.2.9.2 When Generated

The next higher layer of a device generates this primitive to request to conduct an energy scan of channels.

3.2.2.9.3 Effect on Receipt

On receipt of this primitive by a device that is currently joined to a network, the device will temporarily stop operating on the network to conduct an energy scan. To do this, the NLME issues the MLME-SCAN.request primitive to the MAC sub-layer with the ScanType parameter set to indicate an energy detection scan and the ScanChannels and ScanDuration from the NLME request.

3.2.2.10 NLME-ED-SCAN.confirm

This primitive provides the next higher layer results from an energy scan.

3.2.2.10.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-ED-SCAN.confirm	{
	Status
	EnergyDetectList
	}

Table 3.16 specifies the parameters for the service primitive.

Table 3.16 NLME-ED-SCAN.confirm

Name	Type	Valid Range	Description
Status	Status	SUCCESS, or any valid code from the MAC	The status of the request.
EnergyDetectList	List of integers	0x00-0xff for each integer	The list of energy measurements in accordance with [B1], one for each channel.

3.2.2.10.2 When Generated

This primitive is generated by the NLME of a ZigBee device in response to an NLME-ED-SCAN.request. The status indicates the status received from the MAC sub-layer primitive MLME-SCAN.confirm. EnergyDetectList contains the ED scan result (List of integers, 0x00 - 0xff) for the channels scanned in accordance with IEEE 802.15.4-2003.

3.2.2.10.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of an ED scan.

3.2.2.11 NLME-JOIN.request

This primitive allows the next higher layer to request to join or rejoin a network, or to change the operating channel for the device while within an operating network.

3.2.2.11.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

```

NLME-JOIN.request  {
    ExtendedPANId,
    RejoinNetwork,
    ScanChannels,
    ScanDuration,
    CapabilityInformation,
    SecurityEnable
}
    
```

Table 3.17 specifies the parameters for the NLME-JOIN.request primitive.

Table 3.17 NLME-JOIN.request Parameters

Name	Type	Valid Range	Description
ExtendedPANId	Integer	0x0000000000000000 001 – 0xfffffffffffffffe	The 64-bit PAN identifier of the network to join.
RejoinNetwork	Integer	0x00 – 0x03	<p>This parameter controls the method of joining the network.</p> <p>The parameter is 0x00 if the device is requesting to join a network through association.</p> <p>The parameter is 0x01 if the device is joining directly or rejoining the network using the orphaning procedure.</p> <p>The parameter is 0x02 if the device is joining the network using the NWK rejoining procedure.</p> <p>The parameter is 0x03 if the device is to change the operational network channel to that identified in the ScanChannels parameter.</p>
ScanChannels	Bitmap	32-bit field	The five most significant bits (b27,..., b31) are reserved. The 27 least significant bits (b0, b1,... b26) indicate which channels are to be scanned (1=scan, 0=do not scan) for each of the 27 valid channels (see [B1]).

Table 3.17 NLME-JOIN.request Parameters (Continued)

Name	Type	Valid Range	Description
ScanDuration	Integer	0x00-0x0e	A value used to calculate the length of time to spend scanning each channel. The time spent scanning each channel is $(aBaseSuperframeDuration * (2^n + 1))$ symbols, where n is the value of the ScanDuration parameter [B1].
CapabilityInformation	Bitmap	See Table 3.47	The operating capabilities of the device being directly joined.
SecurityEnable	Boolean	TRUE or FALSE	If the value of RejoinNetwork is 0x02 and this is TRUE then the device will try to rejoin securely. Otherwise, this is set to FALSE.

3.2.2.11.2 When Generated

The next higher layer of a device generates this primitive to request to:

- Join a network using the MAC association procedure.
- Join or rejoin a network using the orphaning procedure.
- Join or rejoin a network using the NWK rejoin procedure.
- Switch the operating channel for a device that is joined to a network.

3.2.2.11.3 Effect on Receipt

On receipt of this primitive by a device that is currently joined to a network and with the RejoinNetwork parameter equal to 0x00, the NLME issues an NLME-JOIN.confirm primitive with the Status parameter set to INVALID_REQUEST.

On receipt of this primitive by a device that is not currently joined to a network and with the RejoinNetwork parameter equal to 0x00, the device attempts to join the network specified by the 64-bit ExtendedPANId parameter as described in sub-clause 3.6.1.4.1.1.

If a device receives this primitive and the RejoinNetwork parameter is equal to 0x01, then it attempts to join or rejoin the network using orphaning as described in sub-clause 3.6.1.4.3.2.

On receipt of this primitive with the RejoinNetwork parameter is equal to 0x02, the device attempts to rejoin the network with 64-bit extended PAN ID given by the ExtendedPANId parameter. The procedure for rejoining is given in sub-clause 3.6.1.4.2.

Once the device has successfully joined a network, it will set the value of the *nwkExtendedPANId* NIB attribute to the extended PAN identifier of the network to which it joined.

If a device receives this primitive and the *RejoinNetwork* parameter is equal to 0x03, and the device supports setting the value of *phyCurrentChannel* then the device attempts to switch the operating channel to that provided in the *ScanChannels* parameter. If more than one channel is provided in the *ScanChannels* parameter, the NLME issues an NLME-JOIN.confirm primitive with the *Status* parameter set to *INVALID_REQUEST*. If the channel change is performed successfully, then the device issues a NLME-JOIN.confirm with the *Status* parameter set to *SUCCESS*. If the device does not support the setting of *phyCurrentChannel* directly, then the NLME issues a NLME-JOIN.confirm primitive with the *Status* parameter set to *UNSUPPORTED_ATTRIBUTE*.

If the MAC layer returned an error status during the channel change then this status shall be reported in the *status* field of the NLME-JOIN.confirm primitive.¹⁵

3.2.2.12 NLME-JOIN.indication

This primitive allows the next higher layer of a ZigBee coordinator or ZigBee router to be notified when a new device has successfully joined its network by association or rejoined using the NWK rejoin procedure as described in sub-clause 3.6.1.4.3.

3.2.2.12.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-JOIN.indication	{
	NetworkAddress,
	ExtendedAddress,
	CapabilityInformation,
	RejoinNetwork
	SecureRejoin
	}

15. ZigBee Document 12-0220-04

Table 3.18 specifies the parameters for the NLME-JOIN.indication primitive.

Table 3.18 NLME-JOIN.indication Parameters

Name	Type	Valid Range	Description
NetworkAddress	Network address	0x0001 – 0xffff	The network address of an entity that has been added to the network.
ExtendedAddress	64-bit IEEE address	Any 64-bit, IEEE address	The 64-bit IEEE address of an entity that has been added to the network.
CapabilityInformation	Bitmap	See [B1]	Specifies the operational capabilities of the joining device.
RejoinNetwork	Integer	0x00 - 0x02	<p>The RejoinNetwork parameter indicating the method used to join the network.</p> <p>The parameter is 0x00 if the device joined through association.</p> <p>The parameter is 0x01 if the device joined directly or rejoined using orphaning.</p> <p>The parameter is 0x02 if the device used NWK rejoin.</p>
SecureRejoin	Boolean	TRUE or FALSE	This parameter will be TRUE if the rejoin was performed in a secure manner. Otherwise, this parameter will be FALSE.

3.2.2.12.2 When Generated

This primitive is generated by the NLME of a ZigBee coordinator or router and issued to its next higher layer on successfully adding a new device to the network using the MAC association procedure as shown in Figure 3.35, or on allowing a device to rejoin the network using the NWK rejoining procedure as shown in Figure 3.40.

3.2.2.12.3 Effect on Receipt

On receipt of this primitive, the next higher layer of a ZigBee coordinator or ZigBee router is notified that a new device has joined its network.

3.2.2.13 NLME-JOIN.confirm

This primitive allows the next higher layer to be notified of the results of its request to join a network.

3.2.2.13.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-JOIN.confirm	{
	Status,
	NetworkAddress,
	ExtendedPANID,
	ActiveChannel
	}

Table 3.19 specifies the parameters for the NLME-JOIN.confirm primitive.

Table 3.19 NLME-JOIN.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	INVALID_REQUEST, NOT_PERMITTED, NO_NETWORKS or any status value returned from the MLME- ASSOCIATE.confirm primitive, the MLME- SCAN.confirm primitive or the PLME- SET.confirm. ^a	The status of the corresponding request. ^b
NetworkAddress	Integer	0x0001 – 0xffff and 0xffff	The 16-bit network address that was allocated to this device. This parameter will be equal to 0xffff if the join attempt was unsuccessful.
ExtendedPANID	Integer	0x0000000000000001 – 0xfffffffffffffffe	The 64-bit extended PAN identifier for the network of which the device is now a member.
ActiveChannel	Integer	The number of any channel supported by the PHY (see [B1]).	The value of <i>phyCurrentChannel</i> attribute of the PHY PIB, which is equal to the current channel of the network that has been joined.

a. ZigBee Document 12-0220-04

b. ZigBee Document 12-0220-04

3.2.2.13.2 When Generated

This primitive is generated by the initiating NLME and issued to its next higher layer in response to an NLME-JOIN.request primitive. If the request was successful, the Status parameter will have a value of SUCCESS. Otherwise, the Status parameter indicates an error code of INVALID_REQUEST, NOT_PERMITTED, NO_NETWORKS or any status value returned from either

the MLME-ASSOCIATE.confirm primitive, the MLME-SCAN.confirm primitive or the PLME-SET.confirm primitive. The reasons for these status values are fully described in sub-clause 3.2.2.11.3.¹⁶

3.2.2.13.3 Effect on Receipt

On receipt of this primitive, the next higher layer of the initiating device is notified of the results of its request to join a network using the MAC sub-layer association procedure, to join directly using the MAC sub-layer orphaning procedure, or to re-join a network once it has been orphaned.

3.2.2.14 NLME-DIRECT-JOIN.request

This optional primitive allows the next higher layer of a ZigBee coordinator or router to request to directly join another device to its network.

3.2.2.14.1 Semantics of the Service Primitive

The semantics of this optional primitive are as follows:

NLME-DIRECT-JOIN.request	{
	DeviceAddress,
	CapabilityInformation
	}

Table 3.20 specifies the parameters for the NLME-DIRECT-JOIN.request primitive.

Table 3.20 NLME-DIRECT-JOIN.request Parameters

Name	Type	Valid Range	Description
DeviceAddress	64-bit IEEE address	Any 64-bit IEEE address	The IEEE address of the device to be directly joined.
CapabilityInformation	Bitmap	See Table 3.47	The operating capabilities of the device being directly joined.

3.2.2.14.2 When Generated

The next higher layer of a ZigBee coordinator or router generates this primitive to add a new device directly to its network. This process is completed without any over the air transmissions.

16. ZigBee Document 12-0220-04

3.2.2.14.3 Effect on Receipt

On receipt of this primitive, the NLME will attempt to add the device specified by the DeviceAddress parameter to its neighbor table. The CapabilityInformation parameter will contain a description of the device being joined. The alternate PAN coordinator bit is set to 0 in devices implementing this specification. The device type bit is set to 1 if the device is a ZigBee router, or to 0 if it is an end device. The power source bit is set to 1 if the device is receiving power from the alternating current mains or to 0 otherwise. The receiver on when idle bit is set to 1 if the device does not disable its receiver during idle periods, or to 0 otherwise. The security capability bit is set to 1 if the device is capable of secure operation, or to 0 otherwise.

If the NLME successfully adds the device to its neighbor table, the NLME issues the NLME-DIRECT-JOIN.confirm primitive with a status of SUCCESS. If the NLME finds that the requested device is already present in its neighbor tables, the NLME issues the NLME-DIRECT-JOIN.confirm primitive with a status of ALREADY_PRESENT. If no capacity is available to add a new device to the device list, the NLME issues the NLME-DIRECT-JOIN.confirm primitive with a status of NEIGHBOR_TABLE_FULL.

3.2.2.15 NLME-DIRECT-JOIN.confirm

This primitive allows the next higher layer of a ZigBee coordinator or router to be notified of the results of its request to directly join another device to its network.

3.2.2.15.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-DIRECT-JOIN.confirm	{
	Status,
	DeviceAddress
	}

Table 3.21 specifies the parameters for the NLME-DIRECT-JOIN.confirm primitive.

Table 3.21 NLME-DIRECT-JOIN.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	SUCCESS, ALREADY_PRESENT, NEIGHBOR_TABLE_FULL	The status of the corresponding request.
DeviceAddress	64-bit IEEE address	Any 64-bit, IEEE address	The 64-bit IEEE address in the request to which this is a confirmation.

3.2.2.15.2 When Generated

This primitive is generated by the initiating NLME and issued to its next higher layer in response to an NLME-DIRECT-JOIN.request primitive. If the request was successful, the Status parameter indicates a successful join attempt. Otherwise, the Status parameter indicates an error code of ALREADY_PRESENT or NEIGHBOR_TABLE_FULL. The reasons for these status values are fully described in sub-clause 3.2.2.14.3.

3.2.2.15.3 Effect on Receipt

On receipt of this primitive, the next higher layer of the initiating device is notified of the results of its request to directly join another device to a network.

3.2.2.16 NLME-LEAVE.request

This primitive allows the next higher layer to request that it or another device leaves the network.

3.2.2.16.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-LEAVE.request	{
	DeviceAddress,
	RemoveChildren,
	Rejoin
	}

Table 3.22 specifies the parameters for the NLME-LEAVE.request primitive.

Table 3.22 NLME-LEAVE.request Parameters

Name	Type	Valid Range	Description
------	------	-------------	-------------

Table 3.22 NLME-LEAVE.request Parameters

DeviceAddress	Device address	Any 64-bit, IEEE address	The 64-bit IEEE address of the entity to be removed from the network or NULL if the device removes itself from the network.
RemoveChildren	Boolean	TRUE or FALSE	This parameter has a value of TRUE if the device being asked to leave the network is also being asked to remove its child devices, if any. Otherwise, it has a value of FALSE.
Rejoin	Boolean	TRUE or FALSE	This parameter has a value of TRUE if the device being asked to leave from the current parent is requested to rejoin the network. Otherwise, the parameter has a value of FALSE. Note that the Rejoin parameter is set by the application so cannot be relied upon by the networking layer to indicate whether a Join or Rejoin request will be accepted in the future.

3.2.2.16.2 When Generated

The next higher layer of a device generates this primitive to request to leave the network. The next higher layer of a ZigBee coordinator or router may also generate this primitive to remove a device from the network.

3.2.2.16.3 Effect on Receipt

On receipt of this primitive by the NLME of a device that is not currently joined to a network, the NLME issues the NLME-LEAVE.confirm primitive with a status of INVALID_REQUEST. On receipt of this primitive by the NLME of a device that is currently joined to a network, with the DeviceAddress parameter equal to NULL and the RemoveChildren parameter equal to FALSE, the NLME will remove itself from the network using the procedure described in sub-clause 3.6.1.10.1. The NLME will then clear its routing table and route discovery table and issue an MLME-RESET.request primitive to the MAC sub-layer. The NLME will also set the relationship field of the neighbor table entry corresponding to its former parent to 0x03, indicating no relationship. If the NLME-LEAVE.request primitive is received with the DeviceAddress parameter equal to NULL and the RemoveChildren parameter equal to TRUE, then the NLME will attempt to remove the device's children, as described in sub-clause 3.6.1.10.3.

On receipt of this primitive by a ZigBee coordinator or ZigBee router and with the DeviceAddress parameter not equal to NULL, the NLME determines whether the specified device is a child device. If the requested device does not exist, the NLME issues the NLME-LEAVE.confirm primitive with a status of

UNKNOWN_DEVICE. If the requested device exists, the NLME will attempt to remove it from the network using the procedure described in sub-clause 3.6.1.10.3. If the RemoveChildren parameter is equal to TRUE then the device will be requested to remove its children as well. Following the removal, the NLME will issue the NLME-LEAVE.confirm primitive with the DeviceAddress equal to the 64-bit IEEE address of the removed device and the Status parameter equal to the status delivered by the MCPS-DATA.confirm primitive. If the relationship field of the neighbor table entry corresponding to the leaving device has a value of 0x01 then it will be changed to 0x04 indicating previous child. If it has a value of 0x05, indicating that the child has not yet authenticated, it will be changed to 0x03, indicating no relationship.

3.2.2.17 NLME-LEAVE.indication

This primitive allows the next higher layer of a ZigBee device to be notified if that ZigBee device has left the network or if a neighboring device has left the network.

3.2.2.17.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-LEAVE.indication	{
	DeviceAddress,
	Rejoin
	}

Table 3.23 specifies the parameters for the NLME-LEAVE.indication primitive.

Table 3.23 NLME-LEAVE.indication Parameters

Name	Type	Valid Range	Description
DeviceAddress	64-bit IEEE address	Any 64-bit, IEEE address	The 64-bit IEEE address of an entity that has removed itself from the network or NULL in the case that the device issuing the primitive has been removed from the network by its parent.
Rejoin	Boolean	TRUE or FALSE	This parameter has a value of TRUE if the device being asked to leave the current parent is requested to rejoin the network. Otherwise, this parameter has a value of FALSE.

3.2.2.17.2 When Generated

This primitive is generated by the NLME of a ZigBee coordinator or ZigBee router and issued to its next higher layer on receipt of a broadcast leave command pertaining to a device on its PAN. It is also generated by the NLME of a ZigBee

router or end device and issued to its next higher layer to indicate that it has been successfully removed from the network by its associated router or ZigBee coordinator.

3.2.2.17.3 Effect on Receipt

On receipt of this primitive, the next higher layer of a ZigBee coordinator or ZigBee router is notified that a device, formerly on the network, has left. The primitive can also inform the next higher layer of a ZigBee router or end device that it has been removed from the network by its associated ZigBee router or ZigBee coordinator parent. In this case, the value of the Rejoin parameter indicates to the next higher layer whether the peer entity on the parent device wishes the device that has been removed to rejoin the same network.

3.2.2.18 NLME-LEAVE.confirm

This primitive allows the next higher layer of the initiating device to be notified of the results of its request for itself or another device to leave the network.

3.2.2.18.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-LEAVE.confirm	{
	Status,
	DeviceAddress
	}

Table 3.24 specifies the parameters for the NLME-LEAVE.confirm primitive.

Table 3.24 NLME-LEAVE.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	SUCCESS, INVALID_REQUEST, UNKNOWN_DEVICE or any status returned by the MCPS-DATA.confirm primitive	The status of the corresponding request.
DeviceAddress	64-bit IEEE address	Any 64-bit, IEEE address	The 64-bit IEEE address in the request to which this is a confirmation or null if the device requested to remove itself from the network.

3.2.2.18.2 When Generated

This primitive is generated by the initiating NLME and issued to its next higher layer in response to an NLME-LEAVE.request primitive. If the request was successful, the Status parameter indicates a successful leave attempt. Otherwise,

the Status parameter indicates an error code of INVALID_REQUEST, UNKNOWN_DEVICE or a status delivered by the MCPS-DATA.confirm primitive. The reasons for these status values are fully described in sub-clause 3.2.2.16.3.

3.2.2.18.3 Effect on Receipt

On receipt of this primitive, the next higher layer of the initiating device is notified of the results of its request for itself or a child device to leave the network.

3.2.2.19 NLME-RESET.request

This primitive allows the next higher layer to request the NWK layer to perform a reset operation.

3.2.2.19.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-RESET.request	{ WarmStart }
--------------------	---------------------

Table 3.25 specifies the parameters for this primitive.

Table 3.25 NLME-RESET.request Parameters

Name	Type	Valid Range	Description
WarmStart	Boolean	TRUE or FALSE	This parameter has a value of FALSE if the request is expected reset all stack values to their initial default values. If this value is TRUE, the device is expected to resume operations according to the NIB settings prior to the call.

3.2.2.19.2 When Generated

This primitive is generated by the next higher layer and issued to its NLME to request the NWK layer be reset to its initial condition, or that it resume operations according to its current NIB values prior to this primitive being issued.

3.2.2.19.3 Effect on Receipt

On receipt of this primitive, where the WarmStart parameter has a value of FALSE, the NLME issues the MLME-RESET.request primitive to the MAC sub-layer with the SetDefaultPIB parameter set to TRUE. On receipt of the corresponding MLME-RESET.confirm primitive, the NWK layer resets itself by clearing all internal variables, routing table and route discovery table entries and by setting all NIB attributes to their default values. Once the NWK layer is reset,

the NLME issues the NLME-RESET.confirm with the Status parameter set to SUCCESS if the MAC sub-layer was successfully reset or DISABLE_TRX_FAILURE otherwise.

On receipt of this primitive where WarmStart is set to TRUE, the network layer should not modify any NIB values, but rather should resume normal network operations and consider itself part of the network specified in the NIB. Routing table values and neighbor table values should be cleared. The method by which the network and MAC layers attributes are pre-loaded is left to the implementer.

If this primitive is issued to the NLME of a device that is currently joined to a network, any required leave attempts using the NLME-LEAVE.request primitive should be made *a priori* at the discretion of the next higher layer.

3.2.2.20 NLME-RESET.confirm

This primitive allows the next higher layer of the initiating device to be notified of the results of the request to reset the NWK layer.

3.2.2.20.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-RESET.confirm	{
	Status
	}

Table 3.26 specifies the parameters for this primitive.

Table 3.26 NLME-RESET.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	Any status value returned from the MLME-RESET.confirm primitive (see [B1])	The result of the reset operation

3.2.2.20.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer in response to an NLME-RESET.request primitive. If the request was successful, the Status parameter will have a value of SUCCESS. Otherwise, the Status parameter will indicate an error code of DISABLE_TRX_FAILURE. The reasons for these status values are fully described in sub-clause 3.2.2.19.3.

3.2.2.20.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to reset the NWK layer.

3.2.2.21 Network Layer Reset Message Sequence Chart

Figure 3.2 illustrates the sequence of messages necessary for resetting the NWK layer.

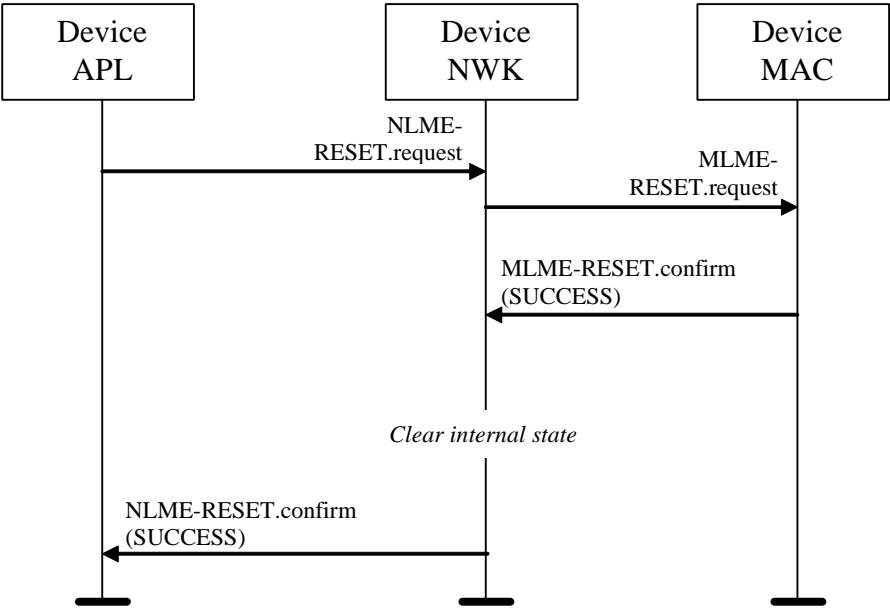


Figure 3.2 Message Sequence Chart for Resetting the Network Layer

3.2.2.22 NLME-SYNC.request

This primitive allows the next higher layer to synchronize or extract data from its ZigBee coordinator or router.

3.2.2.22.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-SYNC.request	{
	Track
	}

Table 3.27 specifies the parameters for this primitive.

Table 3.27 NLME-SYNC.request Parameters

Name	Type	Valid Range	Description
Track	Boolean	TRUE or FALSE	Whether or not the synchronization should be maintained for future beacons.

3.2.2.22.2 When Generated

This primitive is generated whenever the next higher layer wishes to achieve synchronization or check for pending data at its ZigBee coordinator or router.

3.2.2.22.3 Effect on Receipt

If the Track parameter is set to FALSE and the device is operating on a non-beacon enabled network, the NLME issues the MLME-POLL.request primitive to the MAC sub-layer. On receipt of the corresponding MLME-POLL.confirm primitive, the NLME issues the NLME-SYNC.confirm primitive with the Status parameter set to the value reported in the MLME-POLL.confirm.

If the Track parameter is set to FALSE and the device is operating on a beacon enabled network, the NLME first sets the *macAutoRequest* PIB attribute in the MAC sub-layer to TRUE by issuing the MLME-SET.request primitive. It then issues the MLME-SYNC.request primitive with the TrackBeacon parameter set to FALSE. The NLME then issues the NLME-SYNC.confirm primitive with the Status parameter set to SUCCESS.

If the Track parameter is set to TRUE and the device is operating on a non-beacon enabled network, the NLME will issue the NLME-SYNC.confirm primitive with a Status parameter set to INVALID_PARAMETER.

If the Track parameter is set to TRUE and the device is operating on a beacon enabled network, the NLME first sets the *macAutoRequest* PIB attribute in the MAC sub-layer to TRUE by issuing the MLME-SET.request primitive. It then issues the MLME-SYNC.request primitive with the TrackBeacon parameter set to TRUE. The NLME then issues the NLME-SYNC.confirm primitive with the Status parameter set to SUCCESS.

3.2.2.23 NLME-SYNC-LOSS.indication

This primitive allows the next higher layer to be notified of the loss of synchronization at the MAC sub-layer.

3.2.2.23.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-SYNC- LOSS.indication	{ } }
-------------------------------	-------------

This primitive has no parameters.

3.2.2.23.2 When Generated

This primitive is generated upon receipt of a loss of synchronization notification from the MAC sub-layer via the MLME-SYNC-LOSS.indication primitive with a LossReason of BEACON_LOST. This follows a prior NLME-SYNC.request primitive being issued to the NLME.

3.2.2.23.3 Effect on Receipt

The next higher layer is notified of the loss of synchronization with the beacon.

3.2.2.24 NLME-SYNC.confirm

This primitive allows the next higher layer to be notified of the results of its request to synchronize or extract data from its ZigBee coordinator or router.

3.2.2.24.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-SYNC.confirm	{ Status } }
-------------------	-----------------------

Table 3.28 specifies the parameters for this primitive.

Table 3.28 NLME-SYNC.confirm Parameters

Name	Type	Valid Range	Description
Status	Status	SUCCESS, SYNC_FAILURE, INVALID_PARAMETER, or any status value returned from the MLME_POLL.confirm primitive (see [B1])	The result of the request to synchronize with the ZigBee coordinator or router.

3.2.2.24.2 When Generated

This primitive is generated by the initiating NLME and issued to its next higher layer in response to an NLME-SYNC.request primitive. If the request was

successful, the Status parameter indicates a successful synchronization attempt. Otherwise, the Status parameter indicates an error code. The reasons for these status values are fully described in sub-clause 3.2.2.22.2.

3.2.2.24.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to synchronize or extract data from its ZigBee coordinator or router. If the NLME has been successful, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

3.2.2.25 Message Sequence Charts For Synchronization

Figure 3.3 and Figure 3.4 illustrate the sequence of messages necessary for a device to successfully synchronize with a ZigBee coordinator or ZigBee router. Figure 3.3 illustrates the case for a non-beaconing network, and Figure 3.4 illustrates the case for a beaconing network.

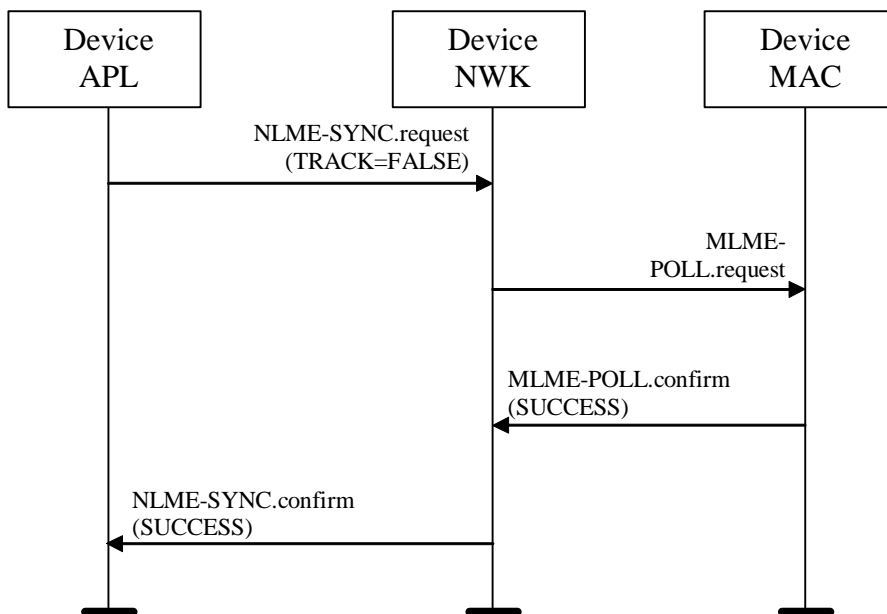


Figure 3.3 Message Sequence Chart for Synchronizing in a Non-Beaconing Network

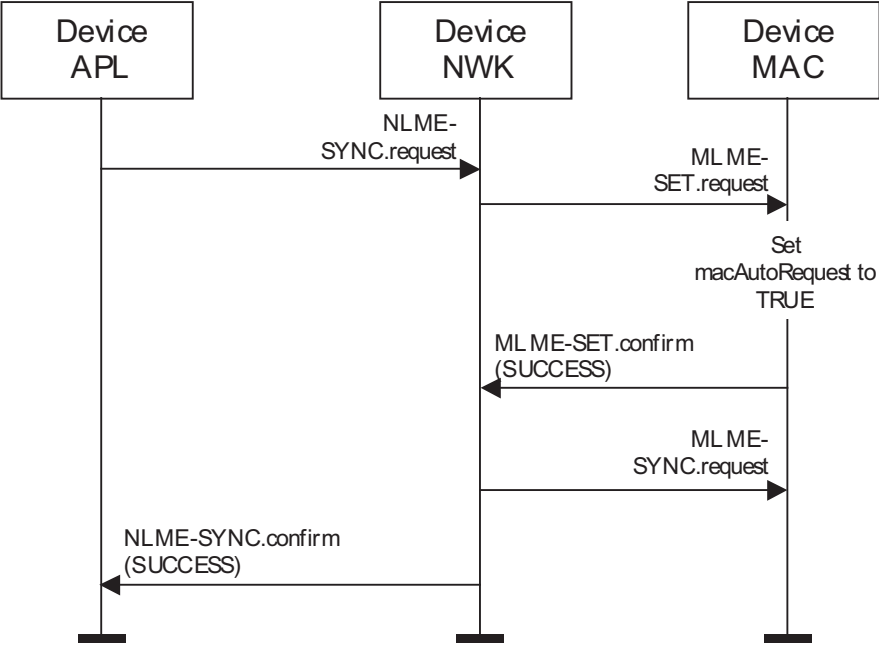


Figure 3.4 Message Sequence Chart for Synchronizing in a Beacon-Enabled Network

3.2.2.26 NLME-GET.request

This primitive allows the next higher layer to read the value of an attribute from the NIB.

3.2.2.26.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-GET.request	{
	NIBAttribute
	}

Table 3.29 specifies the parameters for this primitive.

Table 3.29 NLME-GET.request Parameters

Name	Type	Valid Range	Description
NIBAttribute	Integer	See Table 3.44	The identifier of the NIB attribute to read.

3.2.2.26.2 When Generated

This primitive is generated by the next higher layer and issued to its NLME in order to read an attribute from the NIB.

3.2.2.26.3 Effect on Receipt

On receipt of this primitive, the NLME attempts to retrieve the requested NIB attribute from its database. If the identifier of the NIB attribute is not found in the database, the NLME issues the NLME-GET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE.

If the requested NIB attribute is successfully retrieved, the NLME issues the NLME-GET.confirm primitive with a status of SUCCESS and the NIB attribute identifier and value.

3.2.2.27 NLME-GET.confirm

This primitive reports the results of an attempt to read the value of an attribute from the NIB.

3.2.2.27.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-GET.confirm	{
	Status,
	NIBAttribute,
	NIBAttributeLength,
	NIBAttributeValue
	}

Table 3.30 specifies the parameters for this primitive.

Table 3.30 NLME-GET.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS or UNSUPPORTED_ATTRIBUTE	The results of the request to read a NIB attribute value.
NIBAttribute	Integer	See Table 3.44	The identifier of the NIB attribute that was read.
NIBAttributeLength	Integer	0x0000 – 0xffff	The length, in octets, of the attribute value being returned.
NIBAttributeValue	Various	Attribute specific (see Table 3.44)	The value of the NIB attribute that was read.

3.2.2.27.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer in response to an NLME-GET.request primitive. This primitive returns either a status of SUCCESS, indicating that the request to read a NIB attribute was successful, or an error code of UNSUPPORTED_ATTRIBUTE. The reasons for these status values are fully described in sub-clause 3.2.2.26.3.

3.2.2.27.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to read a NIB attribute. If the request to read a NIB attribute was successful, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

3.2.2.28 NLME-SET.request

This primitive allows the next higher layer to write the value of an attribute into the NIB.

3.2.2.28.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-SET.request	{ NIBAttribute, NIBAttributeLength, NIBAttributeValue }
------------------	---

Table 3.31 specifies the parameters for this primitive.

Table 3.31 NLME-SET.request Parameters

Name	Type	Valid Range	Description
NIBAttribute	Integer	See Table 3.44	The identifier of the NIB attribute to be written.
NIBAttributeLength	Integer	0x0000 – 0xffff	The length, in octets, of the attribute value being set.
NIBAttributeValue	Various	Attribute specific (see Table 3.44)	The value of the NIB attribute that should be written.

3.2.2.28.2 When Generated

This primitive is to be generated by the next higher layer and issued to its NLME in order to write the value of an attribute in the NIB.

3.2.2.28.3 Effect on Receipt

On receipt of this primitive the NLME attempts to write the given value to the indicated NIB attribute in its database. If the NIBAttribute parameter specifies an attribute that is not found in the database, the NLME issues the NLME-SET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE. If the NIBAttributeValue parameter specifies a value that is out of the valid range for the given attribute, the NLME issues the NLME-SET.confirm primitive with a status of INVALID_PARAMETER.

If the requested NIB attribute is successfully written, the NLME issues the NLME-SET.confirm primitive with a status of SUCCESS.

3.2.2.29 NLME-SET.confirm

This primitive reports the results of an attempt to write a value to a NIB attribute.

3.2.2.29.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-SET.confirm	{
	Status,
	NIBAttribute
	}

Table 3.32 specifies the parameters for this primitive.

Table 3.32 NLME-SET.confirm Parameters

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, INVALID_PARAMETER or UNSUPPORTED_ATTRIBUTE	The result of the request to write the NIB attribute.
NIBAttribute	Integer	See Table 3.44	The identifier of the NIB attribute that was written.

3.2.2.29.2 When Generated

This primitive is generated by the NLME and issued to its next higher layer in response to an NLME-SET.request primitive. This primitive returns a status of either SUCCESS, indicating that the requested value was written to the indicated NIB attribute, or an error code of INVALID_PARAMETER or UNSUPPORTED_ATTRIBUTE. The reasons for these status values are fully described in sub-clause 3.2.2.28.3.

3.2.2.29.3 Effect on Receipt

On receipt of this primitive, the next higher layer is notified of the results of its request to write the value of a NIB attribute. If the requested value was written to the indicated NIB attribute, the Status parameter will be set to SUCCESS. Otherwise, the Status parameter indicates the error.

3.2.2.30 NLME-NWK-STATUS.indication

This primitive allows the next higher layer to be notified of network failures.

3.2.2.30.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-NWK-STATUS.indication	{
	Status,
	NetworkAddr
	}

Table 3.33 specifies the parameters for this primitive.

Table 3.33 NLME-NWK-STATUS.indication Parameters

Name	Type	Valid Range	Description
Status	Status	Any network status code (see Table 3.42)	The error code associated with the failure.
NetworkAddr	Integer	0x0000 – 0xffff	The 16-bit network address of the device associated with the status information.

3.2.2.30.2 When Generated

This primitive is generated by the NWK layer on a device and passed to the next higher layer when one of the following occurs:

- The device has failed to discover or repair a route to the destination given by the NetworkAddr parameter.
- The NWK layer on that device has failed to deliver a frame to its end device child with the 16-bit network address given by the NetworkAddr parameter, due to one of the reasons given in Table 3.42.
- The NWK layer has received a network status command frame destined for the device. In this case, the values of the NetworkAddr and Status parameters will reflect the values of the destination address and error code fields of the command frame.

3.2.2.30.3 Effect on Receipt

The next higher layer is notified of a failure to communicate with the identified device.

3.2.2.31 NLME-ROUTE-DISCOVERY.request

This primitive allows the next higher layer to initiate route discovery.

3.2.2.31.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME-ROUTE-DISCOVERY.request	{
	DstAddrMode,
	DstAddr,
	Radius
	NoRouteCache
	}

Table 3.34 specifies the parameters for this primitive.

Table 3.34 NLME-ROUTE-DISCOVERY.request Parameters

Name	Type	Valid Range	Description
DstAddrMode	Integer	0x00 – 0x02	A parameter specifying the kind of destination address provided. The DstAddrMode parameter may take one of the following three values: 0x00 = No destination address 0x01 = 16-bit network address of a multicast group 0x02 = 16-bit network address of an individual device
DstAddr	16-bit network address	Any network address or multicast address	The destination of the route discovery. If the DstAddrMode parameter has a value of 0x00 then no DstAddr will be supplied. This indicates that the route discovery will be a many-to-one discovery with the device issuing the discovery command as a target. If the DstAddrMode parameter has a value of 0x01, indicating multicast route discovery then the destination will be the 16-bit network address of a multicast group. If the DstAddrMode parameter has a value of 0x02, this indicates unicast route discovery. The DstAddr will be the 16-bit network address of a device to be discovered.
Radius	Integer	0x00 – 0xff	This optional parameter describes the number of hops that the route request will travel through the network.
NoRouteCache	Boolean	TRUE or FALSE	In the case where DstAddrMode has a value of zero, indicating many-to-one route discovery, this flag determines whether the NWK should establish a route record table. TRUE = no route record table should be established FALSE = establish a route record table

3.2.2.31.2 When Generated

This primitive is generated by the next higher layer of a ZigBee coordinator or router and issued to its NLME to request the initiation of route discovery.

3.2.2.31.3 Effect on Receipt

On receipt of this primitive by the NLME of a ZigBee end device, the NLME will issue the NLME-ROUTE-DISCOVERY.confirm primitive to the next higher layer with a status value of INVALID_REQUEST.

On receipt of this primitive by the NLME with the DstAddrMode parameter not equal to 0x00 and the DstAddr parameter equal to a broadcast address, the NLME will issue the NLME-ROUTE-DISCOVERY.confirm primitive to the next higher layer with a status value of INVALID_REQUEST.

On receipt of this primitive by the NLME of a ZigBee router or ZigBee coordinator with no routing capacity and with the DstAddrMode parameter equal to 0x01 or 0x02, the NLME will issue the NLME-ROUTE-DISCOVERY.confirm to the next higher layer with a status value of ROUTE_ERROR and a NetworkStatusCode value of 0x04 indicating no routing capacity.

On receipt of this primitive by a ZigBee router or ZigBee coordinator that has routing capacity, with the DstAddrMode parameter equal to 0x02, the NLME will initiate discovery of an unicast route between the current device and the network device with the 16-bit network address given by the DstAddr parameter. The procedure for initiating discovery of a unicast route is outlined in sub-clause 3.6.3.5.1.

On receipt of this primitive by a ZigBee router or ZigBee coordinator that has routing capacity, with the DstAddrMode parameter equal to 0x01, the NLME will first check to see if the device is a member of the multicast group identified by the DstAddr parameter by checking if the *nwkGroupIDTable* attribute of the NIB contains an entry corresponding to the destination address. If the device is a member of the multicast group, then the NLME will immediately issue the NLME-ROUTE-DISCOVERY.confirm primitive with a status value of SUCCESS and discontinue further processing of the NLME-ROUTE-DISCOVERY.request primitive. If the device is not a member of the multicast group, the NLME will initiate discovery of an unicast route between the current device and the multicast group identified by the DstAddr parameter.

On receipt of this primitive on a ZigBee router or ZigBee coordinator with the DstAddrMode parameter equal to 0x00, the NLME will initiate many-to-one route discovery. The procedure for initiating many-to-one route discovery is outlined in sub-clause 3.6.3.5.1.

In each of the three cases of actual route discovery described above, the NLME will initiate route discovery by attempting to transmit a route discovery command frame using the MCPS-DATA.request primitive of the MAC sub-layer. If a value has been supplied for the optional Radius parameter, that value will be placed in the Radius field of the NWK header of the outgoing frame. If a value has not been supplied then the radius field of the NWK header will be set to twice the value of the *nwkMaxDepth* attribute of the NIB as would be the case for data frame

transmissions. If the MAC sub-layer fails, for any reason, to transmit the route request command frame, the NLME will issue the ROUTE-DISCOVERY.confirm primitive to the next higher layer with a Status parameter value equal to that returned by the MCPS-DATA.confirm. If the route discovery command frame is sent successfully and if the DstAddrMode parameter has a value of 0x00, indicating many-to-one route discovery, the NLME will immediately issue the ROUTE-DISCOVERY.confirm primitive with a value of SUCCESS. Otherwise, the NLME will wait until either a route reply command frame is received or the route discovery operation times out as described in sub-clause 3.6.3.5. If a route reply command frame is received before the route discovery operation times out, the NLME will issue the NLME-ROUTE-DISCOVERY.confirm primitive to the next higher layer with a status value of SUCCESS. If the operation times out, it will issue the NLME_ROUTE-DISCOVERY.confirm primitive with a Status of ROUTE_ERROR and with a NetworkStatusCode value reflecting the reason for failure as described in Table 3.42.

3.2.2.32 NLME_ROUTE-DISCOVERY.confirm

This primitive informs the next higher layer about the results of an attempt to initiate route discovery.

3.2.2.32.1 Semantics of the Service Primitive

The semantics of this primitive are as follows:

NLME_ROUTE-DISCOVERY.confirm	{
	Status,
	NetworkStatusCode
	}

Table 3.35 specifies the parameters for the NLME-ROUTE-DISCOVERY.confirm primitive.

Table 3.35 NLME_ROUTE-DISCOVERY.confirm Parameters

Name	Type	Valid Range	Description
Status	status value	INVALID_REQUEST, ROUTE_ERROR or any status value returned by the MCPS-DATA.confirm primitive	The status of an attempt to initiate route discovery.
NetworkSt atusCode	Network status code	See Table 3.42	In the case where the Status parameter has a value of ROUTE_ERROR, this code gives further information about the kind of error that occurred. Otherwise, it should be ignored.

3.2.2.32.2 When Generated

This primitive is generated by the NLME and passed to the next higher layer as a result of an attempt to initiate route discovery.

3.2.2.32.3 Effect on Receipt

The next higher layer is informed of the status of its attempt to initiate route discovery. Possible values for the Status parameter and the circumstances under which they are generated are described in sub-clause 3.2.2.31.3.

3.3 Frame Formats

This sub-clause specifies the format of the NWK frame (NPDU). Each NWK frame consists of the following basic components:

- A NWK header, which comprises frame control, addressing and sequencing information
- A NWK payload, of variable length, which contains information specific to the frame type

The frames in the NWK layer are described as a sequence of fields in a specific order. All frame formats in this sub-clause are depicted in the order in which they are transmitted by the MAC sub-layer, from left to right, where the leftmost bit is transmitted first. Bits within each field are numbered from 0 (leftmost and least significant) to k-1 (rightmost and most significant), where the length of the field is k bits. Fields that are longer than a single octet are sent to the MAC sub-layer in the order from the octet containing the lowest-numbered bits to the octet containing the highest-numbered bits.

3.3.1 General NPDU Frame Format

The NWK frame format is composed of a NWK header and a NWK payload. The fields of the NWK header appear in a fixed order. The NWK frame shall be formatted as illustrated in Figure 3.5.

Octets: 2	2	2	1	1	0/8	0/8	0/1	Variable	Variable
Frame control	Destination address	Source address	Radius	Sequence number	Destination IEEE Address	Source IEEE Address	Multicast control	Source route subframe	Frame payload
NWK Header									Payload

Figure 3.5 General NWK Frame Format

3.3.1.1 Frame Control Field

The frame control field is 16 bits in length and contains information defining the frame type, addressing and sequencing fields and other control flags. The frame control field shall be formatted as illustrated in Figure 3.6.

Bits: 0-1	2-5	6-7	8	9	10	11	12	13-15
Frame type	Protocol version	Discover route	Multicast flag	Security	Source Route	Destination IEEE Address	Source IEEE Address	Reserved

Figure 3.6 Frame Control Field

Table shows the allowable frame control sub-field configurations for NWK data frames. Note that all frames listed below will have a frame type sub-field equal to 00 indicating data and a protocol version sub-field reflecting the version of the ZigBee specification implemented.

Table 3.36 Allowable Frame Control Sub-Field Configurations

Data Transmission Method	Discover Route	Multicast	Security	Destination IEEE Address	Source IEEE Address
Unicast	00 or 01	0	0 or 1	0 or 1	0 or 1
Broadcast	00	0	0 or 1	0	0 or 1
Multicast	00	1	0 or 1	0	0 or 1
Source routed	00	0	0 or 1	0 or 1	0 or 1

3.3.1.1.1 Frame Type Sub-Field

The frame type sub-field is 2 bits in length and shall be set to one of the non-reserved values listed in Table 3.37.

Table 3.37 Values of the Frame Type Sub-Field

Frame Type Value b ₁ b ₀	Frame Type Name
00	Data
01	NWK command
10	Reserved ^a
11	Inter-PAN ^b

a. CCB 1351

b. CCB 1351

3.3.1.1.2 Protocol Version Sub-Field

The protocol version sub-field is 4 bits in length and shall be set to a number reflecting the ZigBee NWK protocol version in use. The protocol version in use on a particular device shall be made available as the value of the NWK constant *nwkProtocolVersion*.

3.3.1.1.3 Discover Route Sub-Field

The discover route sub-field may be used to control route discovery operations for the transit of this frame (see sub-clause 3.6.3.5).

Table 3.38 Values of the Discover Route Sub-Field

Discover Route Field Value	Field Meaning
0x00	Suppress route discovery
0x01	Enable route discovery
0x02, 0x03	Reserved

For NWK layer command frames, the discover route sub-field shall be set to 0x00 indicating suppression of route discovery.

3.3.1.1.4 Multicast Flag Sub-Field

The multicast flag sub-field is 1 bit in length and has the value 0 if the frame is a unicast or broadcast frame and the value 1 if it is a multicast frame. The multicast control field of the NWK header shall be present only if the multicast flag has the value 1.

3.3.1.1.5 Security Sub-Field

The security sub-field shall have a value of 1 if, and only if, the frame is to have NWK security operations enabled. If security for this frame is implemented at another layer or disabled entirely, it shall have a value of 0.

3.3.1.1.6 Source Route Sub-Field

The source route sub-field shall have a value of 1 if and only if a source route subframe is present in the NWK header. If the source route subframe is not present, the source route sub-field shall have a value of 0.

3.3.1.1.7 Destination IEEE Address Sub-Field

The destination IEEE address sub-field shall have a value of 1 if, and only if, the NWK header is to include the full IEEE address of the destination.

3.3.1.1.8 Source IEEE Address Sub-Field

The source IEEE address sub-field shall have a value of 1 if, and only if, the NWK header is to include the full IEEE address of the source device.

3.3.1.2 Destination Address Field

The destination address field shall always be present and shall be 2 octets in length. If the multicast flag sub-field of the frame control field has the value 0, the destination address field shall hold the 16-bit network address of the destination device or a broadcast address (see Table 3.54). If the multicast flag sub-field has the value 1, the destination address field shall hold the 16-bit Group ID of the destination multicast group. Note that the network address of a device shall be set to the value of the *macShortAddress* attribute of the MAC PIB.

3.3.1.3 Source Address Field

The source address field shall always be present. It shall always be 2 octets in length and shall hold the network address of the source device of the frame. Note that the network address of a device shall be set to value of the *macShortAddress* attribute of the MAC PIB.

3.3.1.4 Radius Field

The radius field shall always be present. It will be 1 octet in length and specifies the range of a radius-limited transmission. The field shall be decremented by 1 by each receiving device.

3.3.1.5 Sequence Number Field

The sequence number field is present in every frame and is 1 octet in length. The sequence number value shall be incremented by 1 with each new frame transmitted. The values of the source address and sequence number fields of a frame, taken as a pair, may be used to uniquely identify a frame within the constraints imposed by the sequence number's one-octet range. For more details on the use of the sequence number field, see sub-clause 3.6.2.

3.3.1.6 Destination IEEE Address Field

The destination IEEE address field, if present, contains the 64-bit IEEE address corresponding to the 16-bit network address contained in the destination address field of the NWK header. Upon receipt of a frame containing a 64-bit IEEE address, the contents of the *nwkAddressMap* and neighbor table should be checked for consistency, and updated if necessary. Sub-clause 3.6.1.9.2 describes the actions to take in detecting address conflicts. If the 16-bit network address is a broadcast or multicast address then the destination IEEE address field shall not be present.

3.3.1.7 Source IEEE Address Field

The source IEEE address field, if present, contains the 64-bit IEEE address corresponding to the 16-bit network address contained in the source address field

of the NWK header. Upon receipt of a frame containing a 64-bit IEEE address, the contents of the *nwkAddressMap* and Neighbor Table should be checked for consistency, and updated if necessary. Sub-clause 3.6.1.9.2 describes the actions to take in detecting address conflicts.

3.3.1.8 Multicast Control Field

The multicast control sub-field is 1 octet in length and shall only be present if the multicast flag sub-field has a value of 1. It is divided into three sub-fields as illustrated in Figure 3.7.

Bits: 0 – 1	2 – 4	5 – 7
Multicast mode	NonmemberRadius	MaxNonmemberRadius

Figure 3.7 Multicast Control Field Format

3.3.1.8.1 Multicast Mode Sub-Field

The multicast mode sub-field indicates whether the frame is to be transmitted using member or non-member mode. Member mode is used to propagate multicasts between the devices that are members of the destination group. Non-member mode is used to transmit a multicast frame from a device that is not a member of the multicast group to a device that is a member of the multicast group.

Table 3.39 Values of the Multicast Mode Sub-Field

Multicast Mode Field Value	Field Meaning
0x0	Non-member mode
0x1	Member mode
0x2	Reserved
0x3	Reserved

3.3.1.8.2 NonmemberRadius Sub-Field

The nonmemberradius sub-field indicates the range of a member mode multicast when relayed by devices that are not members of the destination group. Receiving devices that are members of the destination group will set this field to the value of the MaxNonmemberRadius sub-field. The originating device and receiving devices that are not members of the destination group will discard the frame if the NonmemberRadius sub-field has value 0 and will decrement the field if the NonmemberRadius sub-field has a value in the range 0x01 through 0x06. A value of 0x07 indicates an infinite range and is not decremented.

The value of the NonmemberRadius sub-field will never exceed the value of the MaxNonmemberRadius sub-field.

3.3.1.8.3 MaxNonmemberRadius Sub-Field

The maximum value of the NonmemberRadius sub-field for this frame.

3.3.1.9 Source Route Subframe Field

The source route subframe field shall only be present if the source route sub-field of the frame control field has a value of 1. It is divided into three sub-fields as illustrated in Figure 3.8.

Octets: 1	1	Variable
Relay count	Relay index	Relay list

Figure 3.8 Source Route Subframe Format

3.3.1.9.1 Relay Count Sub-Field

The relay count sub-field indicates the number of relays contained in the relay list sub-field of the source route subframe.

3.3.1.9.2 Relay Index

The relay index sub-field indicates the index of the next relay in the relay list sub-field to which the packet will be transmitted. This field is initialized to 1 less than the relay count by the originator of the packet, and is decremented by 1 by each receiving relay.

3.3.1.9.3 Relay List Sub-Field

The relay list sub-field shall contain the list of relay addresses. The relay closest to the destination shall be listed first. The relay closest to the originator shall be listed last.

3.3.1.10 Frame Payload Field

The frame payload field has a variable length and contains information specific to individual frame types.

3.3.2 Format of Individual Frame Types

There are two defined NWK frame types: data and NWK command. Each of these frame types is discussed in the following sub-clauses.

3.3.2.1 Data Frame Format

The data frame shall be formatted as illustrated in Figure 3.9.

Octets: 2	Variable	Variable
Frame control	Routing fields	Data payload
NWK header		NWK payload

Figure 3.9 Data Frame Format

The order of the fields of the data frame shall conform to the order of the general NWK frame format as illustrated in Figure 3.5.

3.3.2.1.1 Data Frame NWK Header Field

The data frame NWK header field shall contain the frame control field and an appropriate combination of routing fields as required.

In the frame control field, the frame type sub-field shall contain the value that indicates a data frame, as shown in Table 3.37. All other sub-fields shall be set according to the intended use of the data frame.

The routing fields shall contain an appropriate combination of address and broadcast fields, depending on the settings in the frame control field (see Figure 3.6).

3.3.2.1.2 Data Payload Field

The data frame data payload field shall contain the sequence of octets, that the next higher layer has requested the NWK layer to transmit.

3.3.2.2 NWK Command Frame Format

The NWK command frame shall be formatted as illustrated in Figure 3.10.

Octets: 2	Variable	1	Variable
Frame control	Routing fields	NWK command identifier	NWK command payload
NWK header		NWK payload	

Figure 3.10 NWK Command Frame Format

The order of the fields of the NWK command frame shall conform to the order of the general NWK frame as illustrated in Figure 3.5.

3.3.2.2.1 NWK Command Frame NWK Header Field

The NWK header field of a NWK command frame shall contain the frame control field and an appropriate combination of routing fields as required.

In the frame control field, the frame type sub-field shall contain the value that indicates a NWK command frame, as shown in Table 3.37. All other sub-fields shall be set according to the intended use of the NWK command frame.

The routing fields shall contain an appropriate combination of address and broadcast fields, depending on the settings in the frame control field.

3.3.2.2.2 NWK Command Identifier Field

The NWK command identifier field indicates the NWK command being used. This field shall be set to one of the non-reserved values listed in Table 3.40.

3.3.2.2.3 NWK Command Payload Field

The NWK command payload field of a NWK command frame shall contain the NWK command itself.

3.4 Command Frames

The command frames defined by the NWK layer are listed in Table 3.40. The following sub-clauses detail how the NLME shall construct the individual commands for transmission.

For each of these commands, the following applies to the NWK header fields unless specifically noted in the clause on NWK header in each command:

- The frame type sub-field of the NWK frame control field shall be set to indicate that this frame is a NWK command frame.
- The discover route sub-field in the NWK header shall be set to suppress route discovery (see Table 3.38).
- The source address field in the NWK header shall be set to the address of the originating device.

Table 3.40 NWK Command Frames

Command Frame Identifier	Command Name	Reference
0x01	Route request	3.4.1
0x02	Route reply	3.4.2
0x03	Network Status	3.4.3
0x04	Leave	3.4.4
0x05	Route Record	3.4.5
0x06	Rejoin request	3.4.6

Table 3.40 NWK Command Frames (Continued)

0x07	Rejoin response	3.4.7
0x08	Link Status	3.4.8
0x09	Network Report	3.4.9
0x0a	Network Update	3.4.10
0x0b – 0xff	Reserved	—

3.4.1 Route Request Command

The route request command allows a device to request other devices within radio range to engage in a search for a particular destination device and establish a state within the network that will allow messages to be routed to that destination more easily and economically in the future. The payload of a route request command shall be formatted as illustrated in Figure 3.11.

Octets: 1	1	2	1	0/8
Command options	Route request identifier	Destination address	Path cost	Destination IEEE Address
NWK command payload				

Figure 3.11 Route Request Command Frame Format

3.4.1.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be included in the MAC frame header:

- The destination PAN identifier shall be set to the PAN identifier of the device sending the route request command.
- The destination address shall be set to the broadcast address of 0xffff.
- The source address and PAN identifier shall be set to the network address and PAN identifier of the device sending the route request command, which may or may not be the device from which the command originated.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. Because the frame is broadcast, no acknowledgment request shall be specified.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.1.2 NWK Header Fields

In order for this route request to reach its destination and for the route discovery process to complete correctly, the following information must be provided:

- The destination address in the NWK header shall be set to the broadcast address for all routers and the coordinator (see Table 3.54).
- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.

3.4.1.3 NWK Payload Fields

The NWK frame payload contains a command identifier field, a command options field, the route request identifier field, the address of the intended destination, an up-to-date summation of the path cost, and the destination IEEE address.

The command frame identifier shall contain the value indicating a route request command frame.

3.4.1.3.1 Command Options Field

The format of the 8-bit command options field is shown in Figure 3.12.

Bit: 0-2	3-4	5	6	7
Reserved	Many-to-one	Destination IEEE address	Multicast	Reserved

Figure 3.12 Route Request Command Options Field

3.4.1.3.1.1 Many-to-One

The many-to-one field shall have one of the non-reserved values shown in Table 3.41.

Table 3.41 Many-to-One Field Values

Value	Description
0	The route request is not a many-to-one route request.
1	The route request is a many-to-one route request and the sender supports a route record table.
2	The route request is a many-to-one route request and the sender does not support a route record table.
3	Reserved

3.4.1.3.1.2 Destination IEEE Address

The destination IEEE address field is a single-bit field. It shall have a value of 1 if, and only if, the command frame contains the destination IEEE address. The Destination IEEE Address field should always be added if it is known.

3.4.1.3.1.3 Multicast Sub-Field

The multicast sub-field is a single-bit field. It shall have a value of 1 if, and only if, the command frame is a request for a route to a multicast group, in which case the destination address field contains the Group ID of the desired group.

3.4.1.3.2 Route Request Identifier

The route request identifier is an 8-bit sequence number for route requests and is incremented by 1 every time the NWK layer on a particular device issues a route request.

3.4.1.3.3 Destination Address

The destination address shall be 2 octets in length and represents the intended destination of the route request command frame.

3.4.1.3.4 Path Cost

The path cost field is eight bits in length and is used to accumulate routing cost information as a route request command frame moves through the network (see sub-clause 3.6.3.5.2).

3.4.1.3.5 Destination IEEE Address

The destination IEEE address shall be 8 octets in length and represents the IEEE address of the destination of the route request command frame. It shall be present only if the destination IEEE address sub-field of the command frame options field has a value of 1.

3.4.2 Route Reply Command

The route reply command allows the specified destination device of a route request command to inform the originator of the route request that the request has been received. It also allows ZigBee routers along the path taken by the route request to establish state information that will enable frames sent from the source

device to the destination device to travel more efficiently. The payload of the route reply command shall be formatted as illustrated in Figure 3.13.

Octets: 1	1	2	2	1	0/8	0/8
Command options	Route request identifier	Originator address	Responder address	Path cost	Originator IEEE address	Responder IEEE address
NWK command payload						

Figure 3.13 Route Reply Command Format

3.4.2.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be included in the MAC frame header:

- The destination MAC address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the first hop in the path back to the originator of the corresponding route request command frame. The destination PAN identifier shall be the same as the PAN identifier of the originator.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the route reply command, which may or may not be the device from which the command originated.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. The transmission options shall be set to require acknowledgment. The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.2.2 NWK Header Fields

In order for this route reply to reach its destination and for the route discovery process to complete correctly, the following information must be provided:

- The source address in the NWK header shall be set to the 16-bit network address of the device transmitting the frame.
- The destination address field in the NWK header shall be set to the network address of the first hop in the path back to the originator of the corresponding route request.
- Since this is a NWK layer command frame, the source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame. The destination IEEE address sub-field of the frame

control field shall also have a value of 1 and the destination IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the first hop in the path back to the originator of the corresponding route request.

- The Sequence Number field in the NWK header shall be created for every hop during the route reply process. The Radius Field shall be set to *nwkMaxDepth* * 2 by the target of the route request. Every hop during the Route Reply process shall decrement the radius by 1.¹⁷ If the value of the radius in the received Route Reply message is 1, the relaying router shall set the radius of the message to 1. The Sequence Number shall be created as if it were a new frame from the device transmitting the frame replacing the sequence number with the device's next available sequence number. The Route Reply frame is not a forwarded frame, but is newly created by each hop during the route reply process.

3.4.2.3 NWK Payload Fields

The NWK frame payload contains a command identifier field, a command options field, the route request identifier, originator and responder addresses and an up-to-date summation of the path cost.

The command frame identifier shall contain the value indicating a route reply command frame.

3.4.2.3.1 Command Options Field

The format of the 8-bit command options field is shown in Figure 3.14.

Bit: 0 – 3	4	5	6	7
Reserved	Originator IEEE address	Responder IEEE address	Multicast	Reserved

Figure 3.14 Route Reply Command Options Field

3.4.2.3.1.1 Originator IEEE Address

The originator IEEE address sub-field is a single-bit field. It shall have a value of 1 if and only if the originator IEEE address field is included in the payload. This bit shall be set when *nwkUniqueAddr* is FALSE.

3.4.2.3.1.2 Responder IEEE Address

The responder IEEE address sub-field is a single-bit field. It shall have a value of 1 if, and only if, the responder IEEE address field is included in the payload. This

17. CCB 1400/1414

bit shall be set when *nwkUniqueAddr* is FALSE and the multicast sub-field is set to 0.

3.4.2.3.1.3 Multicast Sub-Field

The multicast sub-field is a single-bit field. It shall have a value of 1 if and only if the command frame is a reply to a request for a route to a multicast group, in which case the responder address field contains the Group ID of the desired group.

3.4.2.3.2 Route Request Identifier

The route request identifier is the 8-bit sequence number of the route request to which this frame is a reply.

3.4.2.3.3 Originator Address

The originator address field shall be 2 octets in length and shall contain the 16-bit network address of the originator of the route request command frame to which this frame is a reply.

3.4.2.3.4 Responder Address

The responder address field shall be 2 octets in length and shall always be the same as the value in the destination address field of the corresponding route request command frame.

3.4.2.3.5 Path Cost

The path cost field is used to sum link cost as the route reply command frame transits the network (see sub-clause 3.6.3.5.3).

3.4.2.3.6 Originator IEEE Address

The originator IEEE address field shall be 8 octets in length and shall contain the 64-bit address of the originator of the route request command frame to which this frame is a reply. This field shall only be present if the originator IEEE address sub-field of the command options field has a value of 1.

3.4.2.3.7 Responder IEEE Address

The responder IEEE address field shall be 8 octets in length and shall contain the 64-bit address of the destination of the route request command frame to which this frame is a reply. This field shall only be present if the responder IEEE address sub-field of the command options field has a value of 1.

3.4.3 Network Status Command

A device uses the network status command to report errors and other conditions arising in the NWK layer of a particular device to the peer NWK layer entities of

other devices in the network. The NWK status command may be also used to diagnose network problems, *e.g.* address conflicts. The payload of a network status command shall be formatted as illustrated in Figure 3.15.

Octets: 1	2
Status code	Destination address
NWK command payload	

Figure 3.15 Network Status Command Frame Format

3.4.3.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be provided:

- The destination MAC address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the first hop in the path to the destination of the command frame or to the broadcast address 0xffff in the case where the command frame is being broadcast at the NWK layer.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the network status command.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. The transmission options shall not be set to require acknowledgement if the destination MAC address is the broadcast address 0xffff.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.3.2 NWK Header Fields

Network status commands may be either unicast or broadcast. The fields of the NWK header shall be set as follows:

- The source address field shall always be set to the 16-bit network address of the device originating the command frame.
- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.
- When sent in response to a routing error, the destination address field in the NWK header shall be set to the same value as the source address field of the data frame that encountered a forwarding failure.

- If and only if, the network status command frame is not broadcast, the destination IEEE address sub-field of the frame control field shall have a value of 1 and the destination IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE corresponding to the 16-bit network address in the destination address field if this IEEE address is known.

3.4.3.3 NWK Payload Fields

The NWK frame payload of the network status command frame contains a command frame identifier field, a status code field and a destination address field as described below. The command frame identifier shall be set to specify the network status command frame as defined in Table 3.40.

3.4.3.3.1 Status Code

The status code shall be set to one of the non-reserved values shown in Table 3.42.

Table 3.42 Status Codes for Network Status Command Frame

Value	Status Code
0x00	No route available
0x01	Tree link failure
0x02	Non-tree link failure
0x03	Low battery level
0x04	No routing capacity
0x05	No indirect capacity
0x06	Indirect transaction expiry
0x07	Target device unavailable
0x08	Target address unallocated
0x09	Parent link failure
0x0a	Validate route
0x0b	Source route failure
0x0c	Many-to-one route failure
0x0d	Address conflict
0x0e	Verify addresses
0x0f	PAN identifier update
0x10	Network address update

Table 3.42 Status Codes for Network Status Command Frame (Continued)

Value	Status Code
0x11	Bad frame counter
0x12	Bad key sequence number
0x13 – 0xff	Reserved

These status codes are used both as values for the status code field of a network status command frame and as values of the Status parameter of the NLME-NWK-STATUS.indication primitive. A brief explanation of each follows:

- **No route available:** Route discovery and/or repair has been attempted and no route to the intended destination address has been discovered.
- **Tree link failure:** The routing failure occurred as a result of the failure of an attempt to route the frame along the tree.
- **Non-tree link failure:** The routing failure did not occur as a result of an attempt to route along the tree.
- **Low battery level:** The frame was not relayed because the relaying device was running low on battery power.
- **No routing capacity:** The failure occurred because the relaying device has no routing capacity.
- **No indirect capacity:** The failure occurred as the result of an attempt to buffer a frame for a sleeping end device child and the relaying device had no buffer capacity to use.
- **Indirect transaction expiry:** A frame that was buffered on behalf of a sleeping end device child has been dropped as a result of a time-out.
- **Target device unavailable:** An end device child of the relaying device is for some reason unavailable.
- **Target address unallocated:** The frame was addressed to a non-existent end device child of the relaying device.
- **Parent link failure:** The failure occurred as a result of a failure in the RF link to the device's parent. This status is only used locally on a device to indicate loss of communication with the parent.
- **Validate route:** The multicast route identified in the destination address field should be validated as described in sub-clause 3.6.3.6.
- **Source route failure:** Source routing has failed, probably indicating a link failure in one of the source route's links.

- **Many-to-one route failure:** A route established as a result of a many-to-one route request has failed.
- **Address conflict:** The address in the destination address field has been determined to be in use by two or more devices.
- **Verify addresses:** The source device has the IEEE address in the Source IEEE address field and, if the Destination IEEE address field is present, the value it contains is the expected IEEE address of the destination.
- **PAN identifier update:** The operational network PAN identifier of the device has been updated.
- **Network address update:** The network address of the device has been updated.
- **Bad frame counter:** A frame counter reported in a received frame had a value less than or equal to that stored in *nwkSecurityMaterialSet*.
- **Bad key sequence number:** The key sequence number reported in a received frame did not match that of *nwkActiveKeySeqNumber*.

3.4.3.3.2 Destination Address

The destination address field is 2 octets in length and shall be present if, and only if, the network status command frame is being sent in response to a routing failure. In this case, it shall contain the destination address from the data frame that encountered the failure.

3.4.4 Leave Command

The leave command is used by the NLME to inform other devices on the network that a device is leaving the network or else to request that a device leave the network. The payload of the leave command shall be formatted as shown in Figure 3.16

1
Command options
NWK command payload

Figure 3.16 Leave Command Frame Format

3.4.4.1 MAC Data Service Requirement

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be provided:

- The destination MAC address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the neighbor device to which the frame is being sent or else to the MAC broadcast address 0xffff in the case where the NWK header also contains a broadcast address.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the leave command.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. Acknowledgment shall be requested.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.4.2 NWK Header Fields

The NWK header fields of the leave command frame shall be set as follows:

- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.
- If the request sub-field of the command options field is set to 1 then the destination address field in the NWK header shall be set to the network address of the child device being requested to leave.
- If the request sub-field is set to 0 then the destination address field in the NWK header shall be set to 0xfffd so that the indication is received by devices with *macRxOnWhenIdle* equal to TRUE.
- If and only if the command frame is not broadcast, the destination IEEE address sub-field of the frame control field shall be set to 1, and the destination IEEE address field shall be set to the IEEE address of the device being requested to leave.
- The radius field shall be set to 1.

3.4.4.3 NWK Payload Fields

The NWK payload of the leave command frame contains a command frame identifier field and a command options field. The command frame identifier field shall be set to specify the leave command frame as described in Table 3.40.

3.4.4.3.1 Command Options Field

The format of the 8-bit Command Options field is shown in Figure 3.17.

Bit: 0 – 4	5	6	7
Reserved	Rejoin	Request	Remove children

Figure 3.17 Leave Command Options Field

3.4.4.3.1.1 Rejoin Sub-Field

The Rejoin sub-field is a single-bit field. If the value of this sub-field is 1, the device that is leaving from its current parent will rejoin the network. If the value of this sub-field is 0, the device will not rejoin the network.

3.4.4.3.1.2 Request Sub-Field

The request sub-field is a single-bit field. If the value of this sub-field is 1, then the leave command frame is a request for another device to leave the network. If the value of this sub-field is 0, then the leave command frame is an indication that the sending device plans to leave the network.

3.4.4.3.1.3 Remove Children Sub-Field

The remove children sub-field is a single-bit field. If this sub-field has a value of 1, then the children of the device that is leaving the network will also be removed. If this sub-field has a value of 0, then the children of the device leaving the network will not be removed.

3.4.5 Route Record Command

The route record command allows the route taken by a unicast packet through the network to be recorded in the command payload and delivered to the destination device. The payload of the route record command shall be formatted as illustrated in Figure 3.18.

Octets: 1	Variable
Relay count	Relay list
NWK command payload	

Figure 3.18 Route Record Command Format

3.4.5.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be provided:

- The destination MAC address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the neighbor device to which the frame is being sent.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the route record command.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. Acknowledgment shall be requested.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.5.2 NWK Header Fields

The NWK header fields of the route record command frame shall be set as follows:

- If the route record is being initiated as the result of a NLDE-DATA.request primitive from the next higher layer, the source address field shall be set to the 16-bit network address of the originator of the frame. If the route record is being initiated as a result of the relaying of a data frame on behalf of one of the device's end device children, the source address field shall contain the 16-bit network address of that end device child.
- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address corresponding to the 16-bit network address contained in the source address field.
- The destination address field in the NWK header shall be set to the 16-bit network address of the concentrator device that is the destination of the frame.
- The destination IEEE address sub-field of the frame control field shall be set to 1, and the destination IEEE address field shall be set to the IEEE address of the concentrator device that is the destination of the frame, if this address is known.
- The Source Route sub-field of the frame control field shall be set to 0.

3.4.5.3 NWK Payload

The NWK frame payload contains a command identifier field, a relay count field, and a relay list field. The command frame identifier shall contain the value indicating a route record command frame.

3.4.5.3.1 Relay Count Field

This field contains the number of relays in the relay list field of the route record command. If the route record is being initiated as the result of a NLDE-DATA.request primitive from the next higher layer, the relay count field is initialized to 0. If the route record is being initiated as a result of the relaying of a data frame on behalf of one of the device’s end device children, the relay count field is initialized to 1. In either case, it is incremented by each receiving relay.

3.4.5.3.2 Relay List Field

The relay list field is a list of the 16-bit network addresses of the nodes that have relayed the packet. If the route record is being initiated as a result of the relaying of a data frame on behalf of one of the device’s end device children, the initiating device will initialize this field with its own 16-bit network address. Receiving relay nodes append their network address to the list before forwarding the packet.

3.4.6 Rejoin Request Command

The rejoin request command allows a device to rejoin its network. This is normally done in response to a communication failure, such as when an end device can no longer communicate with its original parent.

Octets: 1
Capability Information
NWK command payload

Figure 3.19 Rejoin Request Command Frame Format

3.4.6.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4.-2003, [B1], the following information shall be provided:

- The destination address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the prospective parent.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device transmitting the rejoin command frame.
- The transmission options shall be set to require acknowledgement.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.6.2 NWK Header Fields

The NWK header fields of the rejoin request command frame shall be set as follows:

- The source address field of the NWK header to the 16-bit network address shall be as follows. If the value of the *nwkNetworkAddress* in the NIB is within the valid range, then it shall use that value. If the value of the *nwkNetworkAddress* in the NIB is not within the valid range, then it shall randomly generate a value with the valid range, excluding the value of 0x0000, and use that.¹⁸
- The source IEEE address sub-field of the frame control field shall be set to 1, and the source IEEE address field shall be set to the IEEE address of the device issuing the request.
- The destination address field in the NWK header shall be set to the 16-bit network address of the prospective parent.
- The destination IEEE address sub-field of the frame control field shall be set to 1, and the destination IEEE address field shall be set to the IEEE address of the prospective parent, if this address is known.
- The radius field shall be set to 1.

3.4.6.3 NWK Payload Fields

The NWK frame payload contains a command identifier field and a capability information field. The command frame identifier shall contain the value indicating a rejoin request command frame.

3.4.6.3.1 Capability Information Field

This one-octet field has the format of the capability information field in the association request command in [B1], which is also described in Table 3.47.

3.4.7 Rejoin Response Command

The rejoin response command is sent by a device to inform a child of its network address and rejoin status.

Octets: 2	1
Network address	Rejoin status
NWK command payload	

Figure 3.20 Rejoin Response Command Frame Format

18. CCB 1312

3.4.7.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in [B1], the following information shall be provided:

- The destination MAC address and PAN identifier shall be set to the network address and PAN identifier, respectively, of the device that sent the rejoin request to which this frame is a response.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device that received and processed the rejoin request command frame.
- Acknowledgment shall be requested.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here. The TXOptions shall request ‘indirect transmission’ to be used if the *Receiver on when idle* bit of the *nwkCapabilityInformation* contained in the corresponding rejoin request command is equal to 0x00. Otherwise, ‘direct transmission’ shall be used.

3.4.7.2 NWK Header Fields

The NWK header fields of the rejoin response command frame shall be set as follows:

- The source address field shall be set to the 16-bit network address of the device that is sending the response.
- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the parent device that is sending the response.
- The destination address field of the NWK header shall be set to the current network address of the rejoining device, *i.e.* the device that sent the join request to which this frame is a response.
- The destination IEEE address sub-field of the frame control field shall have a value of 1 and the destination IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the child device that is source of the rejoin request command to which this frame is a response.
- The NWK layer will set the security of the rejoin response command frame to the same level as that of the received rejoin request command frame to which it is a response.

3.4.7.3 NWK Payload Fields

3.4.7.3.1 Network Address Field

If the rejoin was successful, this two-octet field contains the new network address assigned to the rejoining device. If the rejoin was not successful, this field contains the broadcast address (0xffff).

3.4.7.3.2 Rejoin Status Field

This field shall contain one of the nonreserved association status values specified in [B1].

3.4.8 Link Status Command

The link status command frame allows neighboring routers to communicate their incoming link costs to each other as described in sub-clause 3.6.3.4. Link status frames are transmitted as one-hop broadcasts without retries.

3.4.8.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in IEEE 802.15.4-2003 [B1], the following information shall be included in the MAC frame header:

- The destination PAN identifier shall be set to the PAN identifier of the device sending the link status command.
- The destination address must be set to the broadcast address of 0xffff.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the link status command.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. Because the frame is broadcast, no acknowledgment request shall be specified.
- The addressing mode and intra-PAN flags shall be set to support the addressing fields described here.

3.4.8.2 NWK Header Fields

The NWK header field of the link status command frame shall be set as follows:

- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.¹⁹
- The destination address in the NWK header shall be set to the router-only broadcast address (see Table 3.54).
- The destination IEEE address sub-field of the frame control field shall have a value of 0 and the destination IEEE address field of the NWK header shall not be present.
- The radius field shall be set to 1.

3.4.8.3 NWK Payload Fields

The NWK command payload of the link status command shall be formatted as illustrated in Figure 3.21.

Octets: 1	Variable
Command options	Link status list
NWK command payload	

Figure 3.21 Link Status Command Format

3.4.8.3.1 Command Options Field

The format of the 8-bit command options field is shown in Figure 3.22.

Bit: 0 – 4	5	6	7
Entry count	First frame	Last frame	Reserved

Figure 3.22 Link Status Command Options Field

The entry count sub-field of the command options field indicates the number of link status entries present in the link status list. The first frame sub-field is set to 1 if this is the first frame of the sender's link status. The last frame sub-field is set to 1 if this is the last frame of the sender's link status. If the sender's link status fits into a single frame, the first frame and last frame bits shall both be set to 1.

19. CCB 1321

3.4.8.3.2 Link Status List Field

An entry in the link status list is formatted as shown in Figure 3.23.

Octets: 2	1
Neighbor network address	Link status

Figure 3.23 Link Status Entry

Link status entries are sorted in ascending order by network address. If all router neighbors do not fit in a single frame, multiple frames are sent. When sending multiple frames, the last network address in the link status list for frame N is equal to the first network address in the link status list for frame N+1.

Each link status entry contains the network address of a router neighbor, least significant octet first, followed by the link status octet. The incoming cost field contains the device's estimate of the link cost for the neighbor, which is a value between 1 and 7. The outgoing cost field contains the value of the outgoing cost field from the neighbor table.

The link status field in a link status entry is formatted as follows:

Bits: 0-2	3	4-6	7
Incoming cost	Reserved	Outgoing cost	Reserved

3.4.9 Network Report Command

The network report command allows a device to report network events to the device identified by the address contained in the *nwkManagerAddr* in the NIB. Such events are radio channel condition and PAN ID conflicts. The payload of a network report command shall be formatted as illustrated in Figure 3.24.

Octets: 1	8	Variable
Command options (see Figure 3.25)	EPID	Report information
NWK command payload		

Figure 3.24 Network Report Command Frame Format

3.4.9.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service, specified in [B1], the following information shall be included in the MAC frame header:

- The destination PAN identifier shall be set to the PAN identifier of the device sending the network report command.
- The destination address shall be set to the value of the next-hop address field in the routing table entry for which the destination address field has the same value as the *nwkManagerAddr* field in the NIB. If no such routing table entry exists, then the NWK may attempt route discovery as described in sub-clause 3.6.3.5.
- The source MAC address and PAN identifier shall be set to the network address and PAN identifier of the device sending the network report command, which may or may not be the device from which the command originated.
- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security. The transmission options shall be set to require acknowledgment.

3.4.9.2 NWK Header Fields

The NWK header fields of the network report command frame shall be set as follows:

- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.²⁰
- The destination address field in the NWK header shall be set to the 16-bit network address contained in the *nwkManagerAddr* attribute of the NIB.
- The destination IEEE address sub-field of the frame control field shall have a value of 1 and the destination IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the corresponding to the 16-bit network address contained in the *nwkManagerAddr* attribute of the NIB, if this IEEE address is known.

3.4.9.3 NWK Payload Fields

The NWK frame payload contains a command identifier field, a command options field, an EPID field, and a report information payload.

The command frame identifier shall contain the value indicating a network report command frame.

20. CCB 1321

3.4.9.3.1 Command Options Field

The format of the 8-bit command options field is shown in Figure 3.25.

Bits 0 - 4	5 - 7
Report information count	Report command identifier (see Figure 3.26)

Figure 3.25 Network Report Command Options Field

3.4.9.3.1.1 Report Information Count Sub-Field

The report information count sub-field contains an integer indicating the number of records contained within the Report Information field. The size of a record depends in the value of the Report Command Identifier.

3.4.9.3.1.2 Report Command Identifier Sub-Field

The report command identifier sub-field contains an integer indicating the type of report information command. Table 3.26 contains the values that can be inserted into this field.

Report Command Identifier Value	Report Type
0x00	PAN identifier conflict
0x01 - 0x07	Reserved

Figure 3.26 Report Command Identifier Sub-Field

3.4.9.3.2 EPID Field

The EPID field shall contain the 64-bit EPID that identifies the network that the reporting device is a member of.

3.4.9.3.3 Report Information

The report information field provides the information being reported, the format of this field depends upon the value of the Report Command Identifier sub-field.

3.4.9.3.3.1 PAN Identifier Conflict Report

If the value of the Report Command Identifier sub-field indicates a PAN identifier conflict report then the Report Information field will have the format shown in Figure 3.27.

Octets: 2	2	2
1st PAN ID	...	nth PAN ID

Figure 3.27 PAN Identifier Conflict Report

The PAN ID conflict report shall be made up of a list of 16-bit PAN identifiers that are operating in the neighborhood of the reporting device. The number of PAN identifiers in the PAN ID conflict report shall be equal to the value of the report information count sub-field of the command options field.

3.4.10 Network Update Command

The network update command allows the device identified by the *nwkManagerAddr* attribute of the NIB to broadcast the change of configuration information to all devices in the network. For example, broadcasting the fact that the network is about to change its short PAN identifier.

The payload of a network update command shall be formatted as illustrated in Figure 3.28.

Octets: 1	8	1	Variable
Command Options (see Figure 3.25)	EPID	Update Id	Update Information
NWK command payload			

Figure 3.28 Network Update Command Frame Format

3.4.10.1 MAC Data Service Requirements

In order to transmit this command using the MAC data service specified in [B1], the following information shall be included in the MAC frame header:

- The destination PAN identifier shall be set to the old PAN identifier of the ZigBee coordinator in order for the command frame to reach network devices which have not received this update. The destination address shall be set according to the procedures for broadcast transmission outlined in sub-clause 3.6.5.
- The source MAC address and PAN identifier shall be set to the network address and the old PAN identifier of the device sending the network report

command, which may or may not be the device from which the command originated.

- The frame control field shall be set to specify that the frame is a MAC data frame with MAC security disabled, since any secured frame originating from the NWK layer shall use NWK layer security.

3.4.10.2 NWK Header Fields

The NWK header fields of the network update command frame shall be set as follows:

- The source IEEE address sub-field of the frame control field shall be set to 1 and the source IEEE address field of the NWK header shall be present and shall contain the 64-bit IEEE address of the originator of the frame.²¹
- The destination address in the NWK header shall be set to the broadcast address 0xffff.
- The destination IEEE address sub-field of the frame control field shall have a value of 0 and the destination IEEE address field shall not be present in the NWK header.

3.4.10.3 NWK Payload Fields

The NWK frame payload contains a command identifier field, a command options field, an EPID field and an Update Information variable field.

The command frame identifier shall contain the value indicating a network update command frame.

3.4.10.3.1 Command Options Field

The format of the 8-bit command options field is shown in Figure 3.29.

Bits 0 - 4	5 - 7
Update Information Count	Update Command identifier (see Figure 3.30)

Figure 3.29 Network Update Command Options Field

21. CCB 1321

3.4.10.3.1.1 Update Information Count Sub-Field

The update information count sub-field contains an integer indicating the number of records contained within the Update Information field. The size of a record depends on the value of the Update Command Identifier sub-field.

3.4.10.3.1.2 Update Command Identifier Sub-Field

The update command identifier sub-field contains an integer indicating the type of update information command. Figure 3.30 contains the values that can be inserted into this field.

Update Command Identifier Value	Report Type
0x00	PAN Identifier Update
0x01 - 0x07	Reserved

Figure 3.30 Update Command Identifier Sub-Field

3.4.10.3.2 EPID Field

The EPID field shall contain the 64bit EPID that identifies the network that is to be updated.

3.4.10.3.3 Update Id Field

The update Id field will reflect the current value of the *nwkUpdateId* attribute of the device sending the frame.

3.4.10.3.4 Update Information

The update information field provides the information being updated, the format of this field depends upon the value of the Update Command Identifier sub-field.

3.4.10.3.4.1 PAN Identifier Update

If the value of the Update Command Identifier sub-field indicates a PAN identifier update, then the Update Information field shall have the format shown in Figure 3.31.

Octets: 2
New PAN ID

Figure 3.31 PAN Identifier Update

The PAN identifier update shall be made up of a single 16-bit PAN identifier that is the new PAN identifier for this network to use. The Update Information count sub field shall be set equal to 1 as there is only a single PAN identifier contained within the Update Information field.

3.5 Constants and NIB Attributes

3.5.1 NWK Constants

The constants that define the characteristics of the NWK layer are presented in Table 3.43.

Table 3.43 NWK Layer Constants

Constant	Description	Value
<i>nwkcCoordinatorCapable</i>	A Boolean flag indicating whether the device is capable of becoming the ZigBee coordinator. A value of 0x00 indicates that the device is not capable of becoming a coordinator while a value of 0x01 indicates that the device is capable of becoming a coordinator.	Configuration dependent
<i>nwkcDefaultSecurityLevel</i>	The default security level to be used (see Chapter 4).	Defined in stack profile
<i>nwkcMinHeaderOverhead</i>	The minimum number of octets added by the NWK layer to an NSDU.	0x08
<i>nwkcProtocolVersion</i>	The version of the ZigBee NWK protocol in the device.	0x02
<i>nwkcWaitBeforeValidation</i>	The number of OctetDurations, on the originator of a multicast route request, between receiving a route reply and sending a message to validate the route.	0x9c40 (0x500 msec on 2.4 GHz) ^a
<i>nwkcRouteDiscoveryTime</i>	The number of OctetDurations until a route discovery expires.	0xc4b4 (0x2710 msec on 2.4GHz) ^b
<i>nwkcMaxBroadcastJitter</i>	The maximum broadcast jitter time measured in OctetDurations.	0x7d0 (0x40 msec on 2.4GHz) ^c
<i>nwkcInitialRREQRetries</i>	The number of times the first broadcast transmission of a route request command frame is retried.	0x03

Table 3.43 NWK Layer Constants (Continued)

Constant	Description	Value
<i>nwkRREQRetries</i>	The number of times the broadcast transmission of a route request command frame is retried on relay by an intermediate ZigBee router or ZigBee coordinator.	0x02
<i>nwkRREQRetryInterval</i>	The number of OctetDurations between retries of a broadcast route request command frame.	0x1f02 (0xfe msec on 2.4Ghz) ^d
<i>nwkMinRREQJitter</i>	The minimum jitter, in OctetDurations, for broadcast retransmission of a route request command frame.	0x3f (2 msec on 2.4GHz) ^e
<i>nwkMaxRREQJitter</i>	The maximum jitter, in OctetDurations, for broadcast retransmission of a route request command frame.	0xfa0 (128 msec on 2.4GHz) ^f
<i>nwkMACFrameOverhead</i>	The size of the MAC header used by the ZigBee NWK layer.	0x0b

- a. ZigBee Document 12-0220-04
- b. ZigBee Document 12-0220-04
- c. ZigBee Document 12-0220-04
- d. ZigBee Document 12-0220-04
- e. ZigBee Document 12-0220-04
- f. ZigBee Document 12-0220-04

3.5.2 NWK Information Base

The NWK information base (NIB) comprises the attributes required to manage the NWK layer of a device. Each of these attributes can be read or written using the NLME-GET.request and NLME-SET.request primitives, respectively, except for attributes for which the Read Only column contains a value of Yes. In that case, the attributes value may be read using the NLME-GET.request primitive but may not be set using the NLME-SET.request primitive. Generally, these read-only attribute are set using some other mechanism. For example, the *nwkSequenceNumber* attribute is set as specified in sub-clause 3.6.2.1 and

incremented every time the NWK layer sends a frame. The attributes of the NIB are presented in Table 3.44.

Table 3.44 NIB Attributes

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkSequenceNumber</i>	0x81	Integer	Yes	0x00 – 0xff	A sequence number used to identify outgoing frames (see sub-clause 3.6.2).	Random value from within the range
<i>nwkPassiveAckTimeout</i>	0x82	Integer	No	0x000000 – 0xfffff	The maximum time duration in OctetDurations allowed for the parent and all child devices to retransmit a broadcast message (passive acknowledgment time-out).	Defined in stack profile ^a
<i>nwkMaxBroadcastRetries</i>	0x83	Integer	No	0x00 – 0x5	The maximum number of retries allowed after a broadcast transmission failure.	0x03
<i>nwkMaxChildren</i>	0x84	Integer	No	0x00 – 0xff	The number of children a device is allowed to have on its current network Note that when <i>nwkAddrAlloc</i> has a value of 0x02, indicating stochastic addressing, the value of this attribute is implementation-dependent.	Defined in the stack profile
<i>nwkMaxDepth</i>	0x85	Integer	Yes	0x00 – 0xff	The depth a device can have.	Defined in stack profile
<i>nwkMaxRouters</i>	0x86	Integer	No	0x01-0xff	The number of routers any one device is allowed to have as children. This value is determined by the ZigBee coordinator for all devices in the network. If <i>nwkAddrAlloc</i> is 0x02 this value not used.	Defined in stack profile
<i>nwkNeighborTable</i>	0x87	Set	No	Variable	The current set of neighbor table entries in the device (see Table 3.48).	Null set

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkNetworkBroadcastDeliveryTime</i>	0x88	Integer	No	0 – 0xffffffff	Time duration in OctetDurations that a broadcast message needs to encompass the entire network. This is a calculated quantity based on other NIB attributes. The formula is given in sub-clause 3.5.2.1.	Defined in stack profile ^b
<i>nwkReportConstantCost</i>	0x89	Integer	No	0x00-0x01	If this is set to 0, the NWK layer shall calculate link cost from all neighbor nodes using the LQI values reported by the MAC layer; otherwise, it shall report a constant value.	0x00
<i>Reserved</i>	0x8a					
<i>nwkRouteTable</i>	0x8b	Set	No	Variable	The current set of routing table entries in the device (see Table 3.51).	Null set
<i>nwkSymLink</i>	0x8e	Boolean	No	TRUE or FALSE	The current route symmetry setting: TRUE means that routes are considered to be comprised of symmetric links. Backward and forward routes are created during one-route discovery and they are identical. FALSE indicates that routes are not consider to be comprised of symmetric links. Only the forward route is stored during route discovery.	FALSE
<i>nwkCapabilityInformation</i>	0x8f	Bit vector	Yes	See Table 3.47	This field shall contain the device capability information established at network joining time.	0x00

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkAddrAlloc</i>	0x90	Integer	No	0x00 - 0x02	A value that determines the method used to assign addresses: 0x00 = use distributed address allocation 0x01 = reserved 0x02 = use stochastic address allocation	0x00
<i>nwkUseTreeRouting</i>	0x91	Boolean	No	TRUE or FALSE	A flag that determines whether the NWK layer should assume the ability to use hierarchical routing: TRUE = assume the ability to use hierarchical routing. FALSE = never use hierarchical routing.	TRUE
<i>nwkManagerAddr</i>	0x92	Integer	No	0x0000 - 0xffff	The address of the designated network channel manager function.	0x0000
<i>nwkMaxSourceRoute</i>	0x93	Integer	No	0x00 - 0xff	The maximum number of hops in a source route.	0x0c
<i>nwkUpdateId</i>	0x94	Integer	No	0x00 - 0xFF	The value identifying a snapshot of the network settings with which this node is operating with.	0x00
<i>nwkTransactionPersistenceTime</i>	0x95	Integer	No	0x0000 - 0xffff	The maximum time (in superframe periods) that a transaction is stored by a coordinator and indicated in its beacon. This attribute reflects the value of the MAC PIB attribute <i>macTransactionPersistenceTime</i> (see [B1]) and any changes made by the higher layer will be reflected in the MAC PIB attribute value as well.	0x01f4

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkNetworkAddress</i>	0x96	Integer	No	0x0000 - 0xffff7	The 16-bit address that the device uses to communicate with the PAN. This attribute reflects the value of the MAC PIB attribute <i>macShortAddress</i> (see [B1]) and any changes made by the higher layer will be reflected in the MAC PIB attribute value as well.	0xffff
<i>nwkStackProfile</i>	0x97	Integer	No	0x00-0x0f	The identifier of the ZigBee stack profile in use for this device.	
<i>nwkBroadcastTransactionTable</i>	0x98	Set	Yes	-	The current set of broadcast transaction table entries in the device (see Table 3.55)	Null set
<i>nwkGroupIDTable</i>	0x99	Set	No	Variable	The set of group identifiers, in the range 0x0000 - 0xffff, for groups of which this device is a member.	Null Set
<i>nwkExtendedPANID</i>	0x9a	64-bit extended address	No	0x00000000-0xfffffffffffffe	The Extended PAN Identifier for the PAN of which the device is a member. The value 0x0000000000000000 means the Extended PAN Identifier is unknown.	0x0000000000000000
<i>nwkUseMulticast</i>	0x9b	Boolean	No	TRUE or FALSE	A flag determining the layer where multicast messaging occurs. TRUE = multicast occurs at the network layer. FALSE= multicast occurs at the APS layer and using the APS header.	TRUE
<i>nwkRouteRecordTable</i>	0x9c	Set	No	Variable	The route record table (see Table 3.45).	Null Set

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkIsConcentrator</i>	0x9d	Boolean	No	TRUE or FALSE	A flag determining if this device is a concentrator. TRUE = Device is a concentrator. FALSE = Device is not a concentrator.	FALSE
<i>nwkConcentratorRadius</i>	0x9e	Integer	No	0x00 - 0xff	The hop count radius for concentrator route discoveries.	0x0000
<i>nwkConcentratorDiscoveryTime</i>	0x9f	Integer	No	0x00 - 0xff	The time in seconds between concentrator route discoveries. If set to 0x0000, the discoveries are done at start up and by the next higher layer only.	0x0000
<i>nwkSecurityLevel</i>	0xa0		No		Security attribute defined in Chapter 4.	
<i>nwkSecurityMaterialSet</i>	0xa1		No		Security attribute defined in Chapter 4.	
<i>nwkActiveKeySeqNumber</i>	0xa2		No		Security attribute defined in Chapter 4.	
<i>nwkAllFresh</i>	0xa3		No		Security attribute defined in Chapter 4.	
<i>nwkSecureAllFrames</i>	0xa5		No		Security attribute defined in Chapter 4.	
<i>nwkLinkStatusPeriod</i>	0xa6	Integer	No	0x00 - 0xff	The time in seconds between link status command frames.	0x0f
<i>nwkRouterAgeLimit</i>	0xa7	Integer	No	0x00 - 0xff	The number of missed link status command frames before resetting the link costs to zero.	3

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkUniqueAddr</i>	0xa8	Boolean	No	TRUE or FALSE	A flag that determines whether the NWK layer should detect and correct conflicting addresses: TRUE = assume addresses are unique. FALSE = addresses may not be unique.	TRUE
<i>nwkAddressMap</i>	0xa9	Set	No	Variable	The current set of 64-bit IEEE to 16-bit network address map (see Table 3.46).	Null Set
<i>nwkTimeStamp</i>	0xa8C	Boolean	No	TRUE or FALSE	A flag that determines if a time stamp indication is provided on incoming and outgoing packets. TRUE= time indication provided. FALSE = no time indication provided.	FALSE

Table 3.44 NIB Attributes (Continued)

Attribute	Id	Type	Read Only	Range	Description	Default
<i>nwkPANId</i>	0x80	16-bit PAN ID	No	0x0000 - 0xffff	This NIB attribute should, at all times, have the same value as <i>macPANId</i> .	0xffff
<i>nwkTxTotal</i>	0x8D	Integer	No	0x0000 - 0xffff	A count of unicast transmissions made by the NWK layer on this device. Each time the NWK layer transmits a unicast frame, by invoking the MCPS-DATA.request primitive of the MAC sub-layer, it shall increment this counter. When either the NHL performs an NLME-SET.request on this attribute or if the value of <i>nwkTxTotal</i> rolls over past 0xffff the NWK layer shall reset to 0x00 each Transmit Failure field contained in the neighbor table.	0
<i>nwkLeaveRequestAllowed</i>	0xAA	Boolean	No	TRUE or FALSE	This policy determines whether or not a remote NWK leave request command frame received by the local device is accepted.	TRUE ^c

- a. ZigBee Document 12-0220-04
- b. ZigBee Document 12-0220-04
- c. CCB 1279

Table 3.45 Route Record Table Entry Format

Field Name	Field Type	Valid Range	Reference
Network Address	Integer	0x0000-0xffff7	The destination network address for this route record.
Relay Count	Integer	0x0000 - 0xffff	The count of relay nodes from concentrator to the destination.
Path	Set of Network Addresses		The set of network addresses that represent the route in order from the concentrator to the destination.

Table 3.46 Network Address Map

64-bit IEEE Address	16-bit Network address
A valid 64-bit IEEE Address or Null if not known	0x0000 - 0xffff

3.5.2.1 Broadcast Delivery Time

The total delivery time for a broadcast transmission, *i.e.* the time required for a broadcast to be delivered to every device in the network, shall be calculated according to the following formula:

$$nwkBroadcastDeliveryTime = 2 * nwkMaxDepth * ((0.05 + (nwkMaxBroadcastJitter / 2)) + nwkPassiveAckTimeout * nwkBroadcastRetries / 1000)$$

3.6 Functional Description

3.6.1 Network and Device Maintenance

All ZigBee devices shall provide the following functionality:

- Join a network

- Leave a network
- Rejoin a network

Both ZigBee coordinators and routers shall provide the following additional functionality:

- Permit devices to join the network using the following:
 - Association indications from the MAC
 - Explicit join requests from the application
 - Rejoin requests
- Permit devices to leave the network using the following:
 - Network leave command frames
 - Explicit leave requests from the application
- Participate in assignment of logical network addresses
- Maintain a list of neighboring devices

ZigBee coordinators shall provide functionality to establish a new network. ZigBee routers and end devices shall provide the support of portability within a network.

3.6.1.1 Establishing a New Network

The procedure to establish a new network is initiated through use of the NLME-NETWORK-FORMATION.request primitive. Only devices for which the *nwkcCoordinatorCapable* constant has a value of 0x01, and which are not currently joined to a network shall attempt to establish a new network. If this procedure is initiated on any other device, the NLME shall terminate the procedure and notify the next higher layer of the illegal request. This is achieved by issuing the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to INVALID_REQUEST.

When this procedure is initiated, the NLME shall first request that the MAC sub-layer perform an energy detection scan over either a specified set of channels or, by default, the complete set of available channels, as dictated by the PHY layer (see [B1]), to search for possible interferers. A channel scan is initiated by issuing the MLME-SCAN.request primitive to the MAC sub-layer with the ScanType parameter set to energy detection scan. The results are communicated back via the MLME-SCAN.confirm primitive. This scan is not necessary if there is only one channel specified.

On receipt of the results from a successful energy detection scan, the NLME shall order the channels according to increasing energy measurement and discard those channels whose energy levels are beyond an acceptable level. The choice of an

acceptable energy level is left to the implementation. The NLME shall then perform an active scan, by issuing the MLME-SCAN.request primitive with the ScanType parameter set to active scan and ChannelList set to the list of acceptable channels, to search for other ZigBee devices. To determine the best channel on which to establish a new network, the NLME shall review the list of returned PAN descriptors and find the first channel with the lowest number of existing networks, favoring a channel with no detected networks.

If no suitable channel is found, the NLME shall terminate the procedure and notify the next higher layer of the startup failure. This is achieved by issuing the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to STARTUP_FAILURE.

If a suitable channel is found, the NLME shall select a PAN identifier for the new network. To do this the device shall choose a random PAN identifier less than 0xffff that is not already in use on the selected channel. Once the NLME makes its choice, it shall set the *macPANID* attribute in the MAC sub-layer to this value by issuing the MLME-SET.request primitive.

If no unique PAN identifier can be chosen, the NLME shall terminate the procedure and notify the next higher layer of the startup failure by issuing the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to STARTUP_FAILURE.

Once a PAN identifier is selected, the NLME shall select a 16-bit network address equal to 0x0000 and set the *nwkNetworkAddress* attribute of the NIB equal to the selected network address.

Once a network address is selected, the NLME shall check the value of the *nwkExtendedPANId* attribute of the NIB. If this value is 0x0000000000000000 this attribute is initialized with the value of the MAC constant *aExtendedAddress*.

Once the value of the *nwkExtendedPANId* is checked, the NLME shall begin operation of the new PAN by issuing the MLME-START.request primitive to the MAC sub-layer. The parameters of the MLME-START.request primitive shall be set according to those passed in the NLME-NETWORK-FORMATION.request, the results of the channel scan, and the chosen PAN identifier. The status of the PAN startup is communicated back via the MLME-START.confirm primitive.

On receipt of the status of the PAN startup, the NLME shall inform the next higher layer of the status of its request to initialize the ZigBee coordinator. This is achieved by issuing the NLME-NETWORK-FORMATION.confirm primitive with the Status parameter set to the primitive returned in the MLME-START.confirm from the MAC sub-layer.

The procedure to successfully start a new network is illustrated in the message sequence chart (MSC) shown in Figure 3.32.

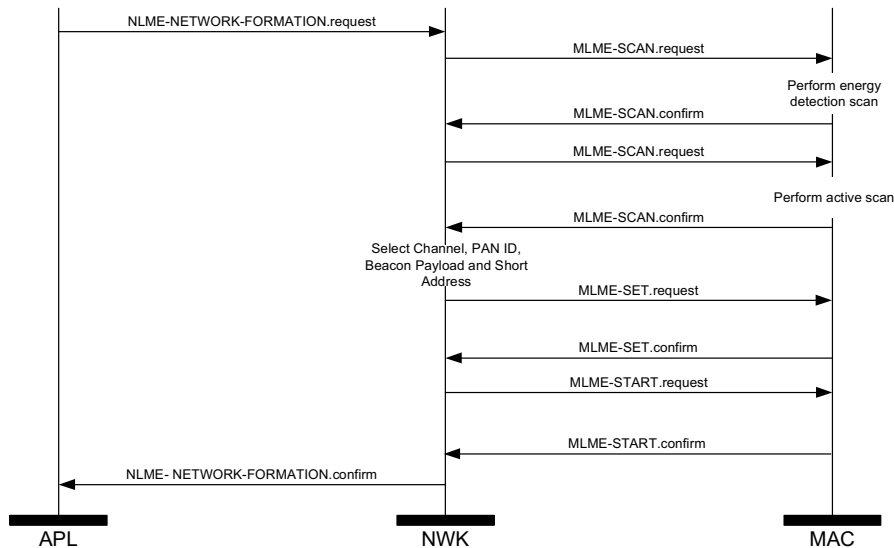


Figure 3.32 Establishing a New Network

3.6.1.2 Permitting Devices to Join a Network

The procedure for permitting devices to join a network is initiated through the NLME-PERMIT-JOINING.request primitive. Only devices that are either the ZigBee coordinator or a ZigBee router shall attempt to permit devices to join the network.

When this procedure is initiated with the PermitDuration parameter set to 0x00, the NLME shall set the *macAssociationPermit* PIB attribute in the MAC sub-layer to FALSE. A MAC sub-layer attribute setting is initiated by issuing the MLME-SET.request primitive.

When this procedure is initiated with the PermitDuration parameter set to a value between 0x01 and 0xfe, the NLME shall set the *macAssociationPermit* PIB attribute in the MAC sub-layer to TRUE. The NLME shall then start a timer to expire after the specified duration. On expiration of this timer, the NLME shall set the *macAssociationPermit* PIB attribute in the MAC sub-layer to FALSE.

When this procedure is initiated with the PermitDuration parameter set to 0xff, the NLME shall set the *macAssociationPermit* PIB attribute in the MAC sub-layer to TRUE for an unlimited amount of time, unless another NLME-PERMIT-JOINING.request primitive is issued.

The procedure for permitting devices to join a network is illustrated in the MSC shown in Figure 3.33.

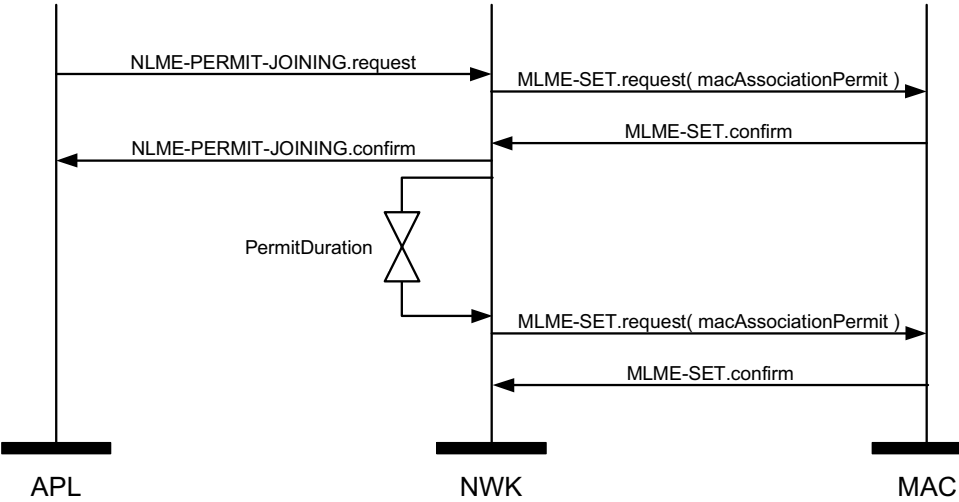


Figure 3.33 Permitting Devices to Join a Network

3.6.1.3 Network Discovery

The NWK layer enables higher layers to discover what networks, if any, are operational in the POS of a device.

The procedure for network discovery shall be initiated by issuing the NLME-NETWORK-DISCOVERY.request primitive with the ScanChannels parameter set to indicate which channels are to be scanned for networks and the ScanDuration parameter set to indicate the length of time to be spent scanning each channel. Upon receipt of this primitive, the NWK layer shall issue an MLME-SCAN.request primitive asking the MAC sub-layer to perform an active scan.

Every beacon frame received during the scan having a non-zero length payload shall cause the MLME-BEACON-NOTIFY.indication primitive to be issued from the MAC sub-layer of the scanning device to its NLME. This primitive includes information such as the addressing information of the beaoning device, whether or not it is permitting association and the beacon payload. (See [B1] for the complete list of parameters). The NLME of the scanning device shall check the protocol ID field in the beacon payload and verify that it matches the ZigBee protocol identifier. If not, the beacon is ignored. Otherwise, the device shall copy the relevant information from each received beacon (see Figure 3.49 for the structure of the beacon payload) into its neighbor table (see Table 3.48 for the contents of a neighbor table entry).

Once the MAC sub-layer signals the completion of the scan by issuing the MLME-SCAN.confirm primitive to the NLME, the NWK layer shall issue the NLME-NETWORK-DISCOVERY.confirm primitive containing a description of

each network that was heard. Every network description contains the ZigBee version, stack profile, Extended PAN Id, PAN Id, logical channel, and information on whether it is permitting joining (see Table 3.8).

3.6.1.4 Joining a Network

For purposes of the ensuing discussion, a parent-child relationship is formed when a device having membership in the network allows a new device to join. On joining, the new device becomes the child, while the first device becomes the parent.

3.6.1.4.1 Joining a Network Through Association

This sub-clause specifies the procedure a device (child) shall follow if it opts to join a network using the underlying association capabilities provided by the MAC, as well as the procedure a ZigBee coordinator or router (parent) shall follow upon receipt of an MLME-ASSOCIATE.request primitive from the MAC.

3.6.1.4.1.1 Child Procedure

The procedure for joining a network using the MAC layer association procedure should be preceded by network discovery as described in sub-clause 3.6.1.3. Upon receipt of the NLME-NETWORK-DISCOVERY.confirm primitive, the next higher layer shall either choose a network to join from the discovered networks or redo the network discovery. Once a network is selected, it shall then issue the NLME-JOIN.request with the RejoinNetwork parameter set to 0x00 and the JoinAsRouter parameter set to indicate whether the device wants to join as a routing device.

Only those devices that are not already joined to a network shall initiate the join procedure. If any other device initiates this procedure, the NLME shall terminate the procedure and notify the next higher layer of the illegal request by issuing the NLME-JOIN.confirm primitive with the Status parameter set to INVALID_REQUEST.

For a device that is not already joined to a network, the NLME-JOIN.request primitive shall cause the NWK layer to search its neighbor table for a suitable parent device, *i.e.* a device for which following conditions are true:

- The device belongs to the network identified by the ExtendedPANId parameter.
- The device is open to join requests and is advertising capacity of the correct device type.
- The link quality for frames received from this device is such that a link cost of at most 3 is produced when calculated as described in sub-clause 3.6.3.1.

- If the neighbor table entry contains a potential parent field for this device, that field shall have a value of 1 indicating that the device is a potential parent.
- The device shall have the most recent update id, where the determination of most recent needs to take into account that the update id will wrap back to zero. In particular the update id given in the beacon payload of the device should be greater than or equal to — again, compensating for wrap — the *nwkUpdateId* attribute of the NIB.

If the neighbor table contains no devices that are suitable parents, the NLME shall respond with an NLME-JOIN.confirm with a Status parameter of NOT_PERMITTED. If the neighbor table has more than one device that could be a suitable parent, the device which is at a minimum depth from the ZigBee coordinator may be chosen. If more than one device has a minimum depth, the NWK layer is free to choose from among them.

Once a suitable parent is identified, the NLME shall issue an MLME-ASSOCIATE.request primitive to the MAC sub-layer. The LogicalChannel parameter of the MLME-ASSOCIATE.request primitive shall be set to that found in the neighbor table entry corresponding to the coordinator address of the potential parent. The bit-fields of the CapabilityInformation parameter shall have the values shown in Table 3.47 and the capability information shall be stored as the value of the *nwkCapabilityInformation* NIB attribute (see Table 3.44). If more than one device meets these requirements, then the joining device may select the parent with the smallest network depth.

Table 3.47 Capability Information Bit-Fields

Bit	Name	Description
0	Alternate PAN coordinator	This field will always have a value of 0 in implementations of this specification.
1	Device type	This field will have a value of 1 if the joining device is a ZigBee router. It will have a value of 0 if the device is a ZigBee end device or else a router-capable device that is joining as an end device.
2	Power source	This field will be set to the value of lowest-order bit of the PowerSource parameter passed to the NLME-JOIN-request primitive. The values are: 0x01 = Mains-powered device 0x00 = other power source

Table 3.47 Capability Information Bit-Fields (Continued)

Bit	Name	Description
3	Receiver on when idle	This field will be set to the value of the lowest-order bit of the RxOnWhenIdle parameter passed to the NLME-JOIN.request primitive. 0x01 = The receiver is enabled when the device is idle 0x00 = The receiver may be disabled when the device is idle
4 – 5	Reserved	This field will always have a value of 0 in implementations of this specification.
6	Security capability	This field shall have a value of 0 if the device is operating in Standard Security Mode and a value of 1 if the device is operating in High Security Mode. Note that this overrides the default meaning specified in [B1].
7	Allocate address	This field will have a value of 1 in implementations of this specification, indicating that the joining device must be issued a 16-bit network address, except in the case where a device has self-selected its address while using the NWK rejoin command to join a network for the first time in a secure manner. In this case, it shall have a value of 0.

Otherwise, the NLME issues the NLME-JOIN.confirm with the Status parameter set to the Status parameter value returned from the MLME-ASSOCIATE.confirm primitive.

If the RejoinNetwork parameter is 0x00 and the JoinAsRouter parameter is set to TRUE, the device will function as a ZigBee router in the network. If the JoinAsRouter parameter is FALSE, then it will join as an end device and not participate in routing.

The addressing parameters in the MLME-ASSOCIATE.request primitive (see Chapter 2) shall be set to contain the addressing information for the device chosen from the neighbor table. The status of the association is communicated back to the NLME via the MLME-ASSOCIATE.confirm primitive.

If the attempt to join was unsuccessful, the NWK layer shall receive an MLME-ASSOCIATE.confirm primitive from the MAC sub-layer with the Status parameter indicating the error. If the Status parameter indicates a refusal to permit joining on the part of the neighboring device (that is, PAN at capacity or PAN access denied), then the device attempting to join should set the Potential parent

bit to 0 in the corresponding neighbor table entry to indicate a failed join attempt. Setting the Potential parent bit to 0 ensures that the NWK layer shall not issue another request to associate to the same neighboring device. The Potential parent bit should be set to 1 for every entry in the neighbor table each time an MLME-SCAN.request primitive is issued.

A join request may also be unsuccessful, if the potential parent is not allowing new routers to associate (for example, the maximum number of routers, *nwkMaxRouters* may already have associated with the device) and the joining device has set the JoinAsRouter parameter to TRUE. In this case, the NLME-JOIN.confirm primitive will indicate a status of NOT_PERMITTED. In this case, the child device's application may wish to attempt to join again as an end device instead, by issuing another NLME-JOIN.request with the JoinAsRouter parameter set to FALSE.

If the attempt to join was unsuccessful, the NLME shall attempt to find another suitable parent from the neighbor table. If no such device could be found, the NLME shall issue the NLME-JOIN.confirm primitive with the Status parameter set to the value returned in the MLME-ASSOCIATE.confirm primitive.

If the attempt to join was unsuccessful and there is a second neighboring device that could be a suitable parent, the NWK layer shall initiate the MAC sub-layer association procedure with the second device. The NWK layer shall repeat this procedure until it either joins the PAN successfully or exhausts its options to join the PAN.

If the device cannot successfully join the PAN specified by the next higher layer, the NLME shall terminate the procedure by issuing the NLME-JOIN.confirm primitive with the Status parameter set to the value returned in the last received MLME-ASSOCIATE.confirm primitive. In this case, the device shall not receive a valid logical address and shall not be permitted to transmit on the network.

If the attempt to join was successful, the NWK shall issue the NLME-JOIN.confirm primitive with a status value of SUCCESS. In this case, the MLME-ASSOCIATE.confirm primitive received by the NWK layer shall contain a 16-bit logical address unique to that network which the child can use in future transmissions. The NWK layer shall then set the Relationship field in the corresponding neighbor table entry to indicate that the neighbor is its parent. By this time, the parent shall have added the new device to its neighbor table. Furthermore, the NWK layer will update the values of *nwkNetworkAddress*, *nwkUpdateId* and *nwkPANId* in the NIB.

If the device is attempting to join a secure network and it is a router, it will need to wait until its parent has authenticated it before transmitting beacons. The device shall therefore wait for an NLME-START-ROUTER.request primitive to be issued from the next higher layer. Upon receipt of this primitive, the NLME shall issue an MLME-START.request primitive if it is a router. If the NLME-START-

ROUTER.request primitive is issued on an end device, the NWK layer shall issue an NLME-START-ROUTER.confirm primitive with the status value set to INVALID_REQUEST.

Once the device has successfully joined the network, if it is a router and the next higher layer has issued a NLME-START-ROUTER.request, the NWK layer shall issue the MLME-START.request primitive to its MAC sub-layer. The PANId, LogicalChannel, BeaconOrder and SuperframeOrder parameters shall be set equal to the corresponding values held in the neighbor table entry for its parent. The network depth is set to one more than the parent network depth unless the parent network depth has a value of 0x0f, *i.e.* the maximum value for the 4-bit device depth field in the beacon payload. In this case, the network depth shall also be set to 0x0f. The PANCoordinator and CoordRealignment parameters shall both be set to FALSE. Upon receipt of the MLME-START.confirm primitive, the NWK layer shall issue an NLME-START-ROUTER.confirm primitive with the same status value.

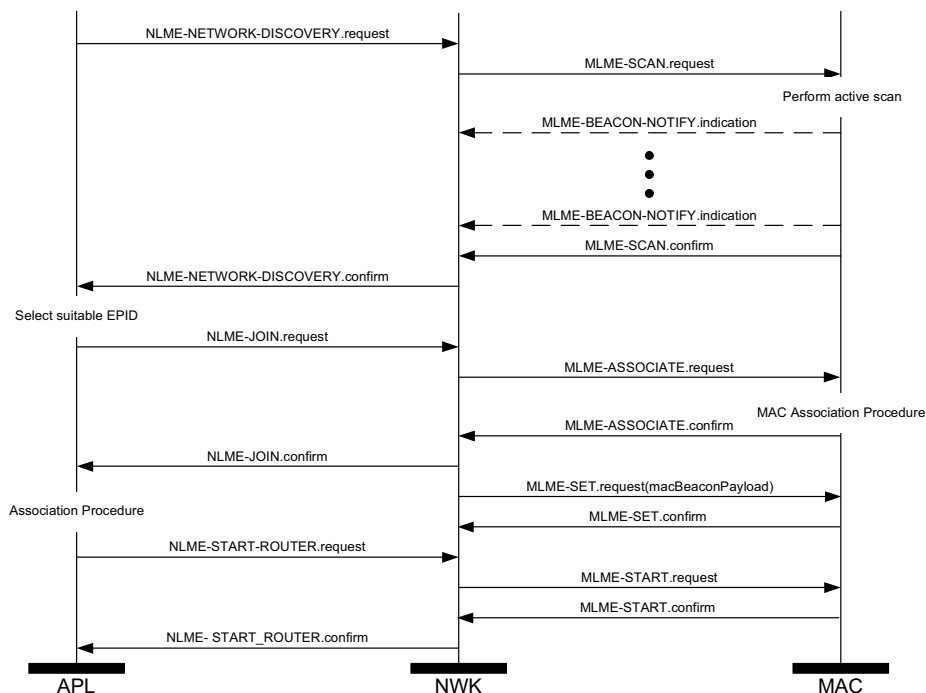


Figure 3.34 Procedure for Joining a Network Through Association

3.6.1.4.1.2 Parent Procedure

The procedure for a ZigBee coordinator or router to join a device to its network using the MAC sub-layer association procedure is initiated by the MLME-ASSOCIATE.indication primitive arriving from the MAC sub-layer. Only those devices that are either a ZigBee coordinator or a ZigBee router and that are permitting devices to join the network shall initiate this procedure. If this procedure is initiated on any other device, the NLME shall terminate the procedure.

When this procedure is initiated, the NLME of a potential parent shall first determine whether the device wishing to join already exists on its network. To do this, the NLME shall search its neighbor table in order to determine whether a matching 64-bit, extended address can be found. If an extended address match is found, the NLME shall check that the supplied DeviceCapabilities match the device type on record in the neighbor table. If the device type also matches the NLME, it shall then obtain the corresponding 16-bit network address and issue an association response to the MAC sub-layer. If a device type match is not found the NLME shall remove all records of the device in its neighbor table and restart processing of the MLME-ASSOCIATION.indication. If an extended address match is not found, the NLME shall, if possible, allocate a 16-bit network address for the new device. See sub-clause 3.6.1.6 and sub-clause 3.6.1.7 for an explanation of the address assignment mechanisms.

If the potential parent does not have the capacity to accept more children, the NLME shall terminate the procedure and indicate this fact in the subsequent MLME-ASSOCIATE.response primitive to the MAC sub-layer. The Status parameter of this primitive shall indicate that the PAN is at capacity.

If the request to join is granted, the NLME of the parent shall create a new entry for the child in its neighbor table using the supplied device information and indicate a successful association in the subsequent MLME-ASSOCIATE.response primitive to the MAC sub-layer. If the value of *nwkSecurityLevel* is 0x00, the relationship field of the new neighbor table entry shall be set to the value 0x01 indicating that the neighbor is a child; otherwise, it shall be set to 0x05 indicating an unauthenticated child. The status of the response transmission to the child is communicated back to the network layer via the MLME-COMM-STATUS.indication primitive.

If the transmission was unsuccessful (*i.e.* the MLME-COMM-STATUS.indication primitive contained a Status parameter not equal to SUCCESS), the NLME shall terminate the procedure. If the transmission was successful, the NLME shall notify the next higher layer that a child has just joined the network by issuing the NLME-JOIN.indication primitive.

The procedure for successfully joining a device to the network is illustrated in the MSC shown in Figure 3.35.

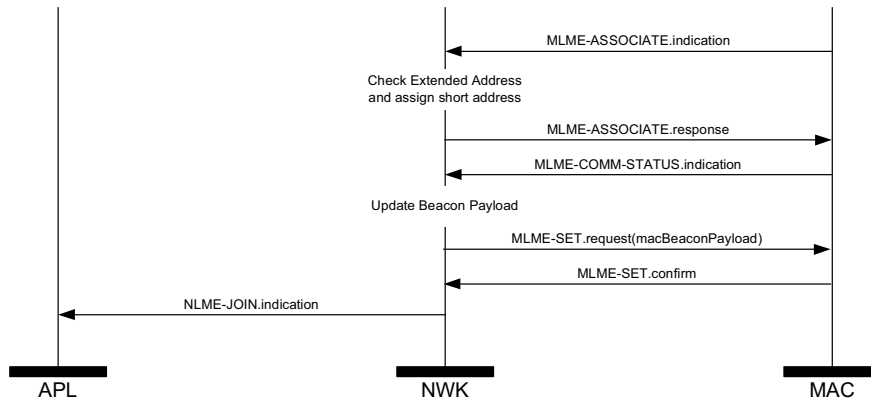


Figure 3.35 Procedure for Handling a Join Request

3.6.1.4.2 Joining or Rejoining a Network Using NWK Rejoin

Devices that have lost all connection to the network, for example a ZED that can no longer communicate successfully with its parent, can rejoin the network using the NWK rejoin request and NWK rejoin response commands. The rejoining procedure is identical to the association procedure described in the previous section, except that the MAC association procedure is replaced by an exchange involving the rejoin request and rejoin response commands, and, because NWK commands make use of NWK security, no authentication step is performed. Using these commands instead of the MAC procedure allows a device to rejoin a network that does not currently allow new devices to join.

Devices that are joining a network for the first time may also use a variant of this procedure as described in the following sub-clauses.

3.6.1.4.2.1 Child Procedure

The procedure for joining or rejoining a network using the NWK rejoin procedure shall be initiated by issuing the NLME-JOIN.request primitive, as shown in Figure 3.36, with the RejoinNetwork parameter set to 0x02 and the ExtendedPANId parameter set to the ExtendedPANId of the network to rejoin. The device type field of the CapabilityInformation parameter shall be set to 1 if the device is intended to join as a router and to 0 otherwise. If the value of the *nwkNetworkAddress* value in the NIB is within the valid range defined for that value, it shall use *nwkNetworkAddress* when issuing the Rejoin Request command. If the *nwkNetworkAddress* is NOT within the valid range, it shall randomly generate a short address within the valid range, excluding the value of 0x0000, and use that for the Rejoin Request command.²²

22. CCB 1312

The ScanChannels parameter shall be set to indicate which channels are to be scanned to locate this network and the ScanDuration parameter set to indicate the length of time to be spent scanning each channel.

Upon receipt of this primitive, the NWK layer shall issue an MLME-SCAN.request primitive asking the MAC sub-layer to perform an active scan.

Every beacon frame received during the scan having a non-zero length payload shall cause the MLME-BEACON-NOTIFY.indication primitive to be issued from the MAC sub-layer of the scanning device to its NLME. The NLME of the scanning device shall check the ExtendedPANId contained within the beacon payload to see if it is of the correct value. If not, the beacon is ignored. Otherwise, the device shall copy the relevant information from each received beacon (see Figure 3.49 for the structure of the beacon payload) into its neighbor table (see Table 3.48 and Table 3.49 for the contents of a neighbor table entry).

Once the MAC sub-layer signals the completion of the scan by issuing the MLME-SCAN.confirm primitive to the NLME, the NWK layer shall search its neighbor table for a suitable parent device. A suitable parent device shall advertise device capacity of the type requested in the JoinAsRouter parameter, shall have the most recent update id, where the determination of most recent update id must take into account that the update id will wrap back to zero, and shall have a link cost (see sub-clause 3.6.3.1) of 3, at most. If the neighbor table contains no devices that are suitable parents, the NLME shall respond with an NLME-JOIN.confirm with a Status parameter of NOT_PERMITTED. If the neighbor table has more than one device that could be a suitable parent, the device which is at a minimum depth from the ZigBee coordinator shall be chosen.

Once a suitable parent is identified, the NLME shall construct a NWK rejoin request command frame. The destination address field of the NWK header shall have a value equal to the 16-bit network address of the parent candidate chosen from the neighbor table. The source address field of the NWK header shall be set to the value of the *nwkNetworkAddress* attribute of the NIB. Both the source IEEE address field and the destination IEEE address field shall be present in the NWK header. If the device is joining this network for the first time, and the value of the *nwkNetworkAddress* attribute of its NIB has a value of 0xffff indicating that it is not currently joined to a network, the device shall select a 16-bit network address for itself and set the *nwkNetworkAddress* attribute to this value. The address should be randomly selected according to the procedures outlined in sub-clause 3.6.1.7. In this case, and in any case where the *nwkAddrAlloc* attribute of the NIB has a value of 0x02 indicating stochastic addressing, the allocate address sub-field of the capability information field of the command payload shall be set to 0 indicating a self-selected address.

After the successful transmission of the rejoin request command using the MAC data service, the network layer shall load a countdown timer with a value of *aResponseWaitTime* ([B1]). If this timer elapses before a rejoin response

command frame is received, then the rejoin was unsuccessful. If the receiver on when idle field of the CapabilityInformation parameter is equal to 0, the device shall issue a MLME-POLL.request to the potential parent to retrieve the rejoin response command. If the receiver on when idle field is equal to 1, polling is not required.

Note: Polling more than once before *aResponseWaitTime* ([B1]) elapses is permitted.

On receipt of a rejoin response command frame, after the above procedure or at any other time, the device shall check the destination IEEE address field and the source IEEE address fields of the command frame NWK header. If the destination IEEE address field is not equal in value to the IEEE address of the receiving device or if the source IEEE address field is not equal in value to the IEEE address of the most recent potential parent to which a rejoin request command frame was sent (or the current parent in the case of an unsolicited rejoin response), then the rejoin response command frame shall be discarded without further processing.

If the rejoin status field within the rejoin response command frame indicates a refusal to permit rejoining on the part of the neighboring device (that is, PAN at capacity or PAN access denied), then the device attempting to rejoin should set the potential parent bit to 0 in the corresponding neighbor table entry to indicate a failed join attempt. Setting the potential parent bit to 0 ensures that the NWK layer will not issue another request to rejoin to the same neighboring device. If the attempt to join was unsuccessful, the NLME shall attempt to find another suitable parent from the neighbor table. If no such device can be found, the NLME shall issue the NLME-JOIN.confirm primitive with the Status parameter set to NOT_PERMITTED. If the attempt to join is unsuccessful and there is a second neighboring device that could be a suitable parent, the NWK layer shall initiate the NWK rejoin procedure with the second device. The NWK layer shall repeat this procedure until it either rejoins the PAN successfully or exhausts its options to rejoin the PAN. If the device cannot successfully rejoin the PAN specified by the next higher layer, the NLME shall terminate the procedure by issuing the NLME-JOIN.confirm primitive with the Status parameter set to NOT_PERMITTED. In this case, the device shall not receive a valid logical address and shall not be permitted to transmit on the network. If the attempt to rejoin was successful, the NWK rejoin response command received by the NWK layer shall contain a 16-bit logical address unique to that network, which the child can use in future transmissions. Note that this address may be identical to the current 16-bit network address of the device stored in the *nwkNetworkAddress* attribute of the NIB. The NWK layer shall then set the relationship field in the corresponding neighbor table entry to indicate that the neighbor is its parent. By this time, the parent shall have added the new device to its neighbor table. Furthermore, the NWK layer shall update the values of *nwkNetworkAddress*, *nwkUpdateId*, and *nwkPANId* in the NIB if necessary.

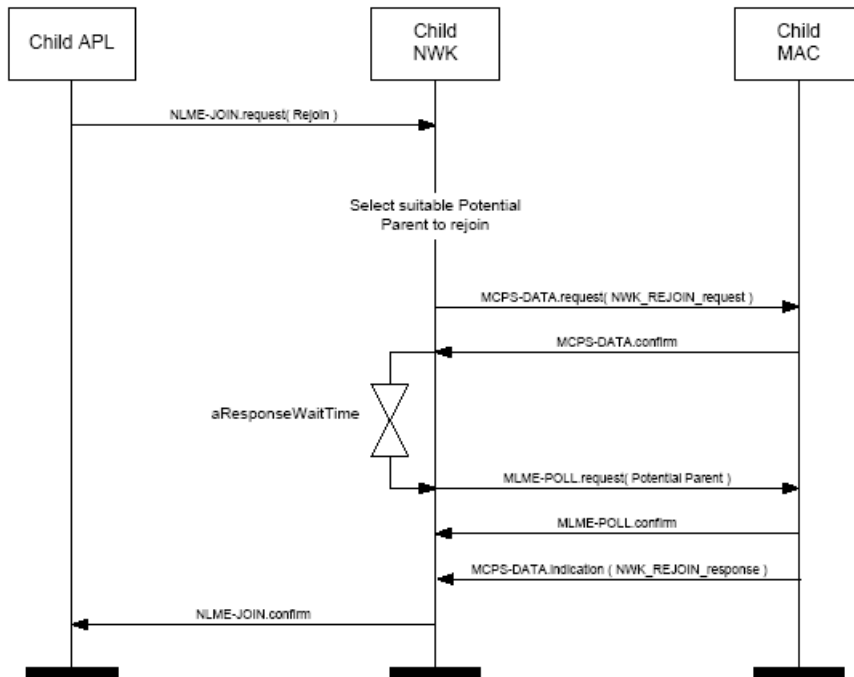


Figure 3.36 Child Rejoin Procedure

3.6.1.4.2.2 Parent Procedure

The procedure for a ZigBee coordinator or router to rejoin a device to its network using the NWK rejoin procedure is initiated by the arrival of a NWK layer rejoin command frame via the MAC data service. Only those devices that are either ZigBee coordinators or ZigBee routers shall initiate this procedure. If this procedure is initiated on any other device, the NLME shall terminate the procedure. When this procedure is initiated, the NLME of a potential parent shall first determine whether it already has knowledge of the requesting device. To do this, the NLME shall search its neighbor table in order to determine whether a matching 64-bit, extended address can be found. If an extended address match is found, the NLME shall check that the supplied DeviceCapabilities match the device type on record in the neighbor table. If the device type matches, the NLME shall consider the join attempt successful and use the 16-bit network address found in its neighbor table as the network address of the joining device. If a device type match is not found, the NLME shall remove all records of the device in its neighbor table and restart processing of the NWK layer rejoin command.

If the potential parent does not have the capacity to accept the joining device, the NLME shall terminate the procedure and indicate this fact in the subsequent rejoin

response command. The Status parameter of this command shall indicate that the PAN is at capacity.

If the request to rejoin is granted, the NLME of the parent shall create a new entry for the child in its neighbor table, or modify the existing entry if one such already exists, using the supplied device information, and indicate a successful rejoin by replying to the requesting device with a NWK rejoin response command. If the *nwkAddrAlloc* attribute of the NIB has a value of 0x00, indicating tree addressing, the NLME shall allocate new a 16-bit network address for the joining device. See sub-clause 3.6.1.6 and sub-clause 3.6.1.7 for an explanation of the address assignment mechanisms.

If the *nwkAddrAlloc* attribute of the NIB does not have a value of 0x00, the allocate address sub-field of the capabilities information field of the rejoin request command frame payload may have a value of 0 indicating a self-assigned or pre-existing network address. In this case, as is the case with all NWK command frames, the 16-bit network address in the source address field of the NWK header, in combination with the 64-bit IEEE address from the source IEEE address field of the network header should be checked for address conflicts as described in sub-clause 3.6.1.9. If an address conflict is discovered, a new, and non-conflicting, address shall be chosen for the joining device and shall be placed in the network address field of command frame payload of the outgoing rejoin response command frame. Otherwise, the contents of the source address field of the incoming rejoin request command frame shall be placed in the network address field of the command frame payload of the outgoing rejoin response command frame.

The NLME shall then notify the next higher layer that a child has just rejoined the network by issuing the NLME-JOIN.indication primitive. The procedure for successfully rejoining a device to the network is illustrated in the MSC shown in Figure 3.37.

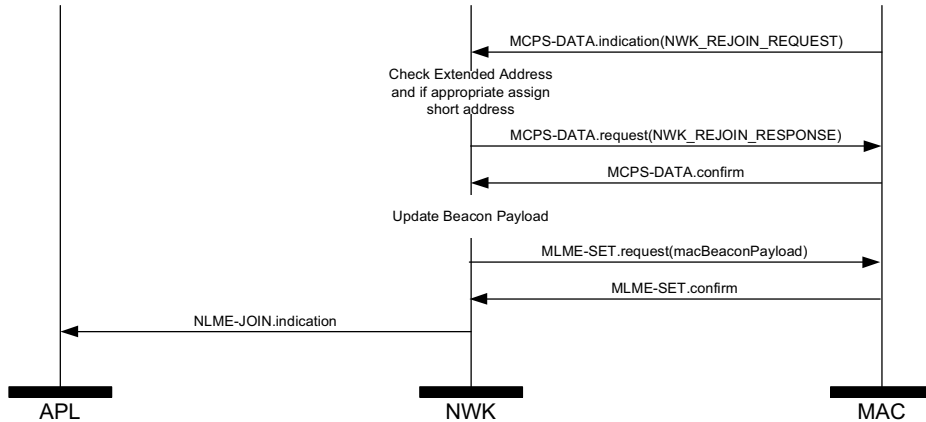


Figure 3.37 Parent Rejoin Procedure

3.6.1.4.3 Joining a Network Directly

This sub-clause specifies how a device can be directly added to a network by a previously designated parent device (ZigBee coordinator or router). In this case, the parent device is preconfigured with the 64-bit address of the child device. The following text describes how this prior address knowledge may be used to establish the parent-child relationship.

The procedure for a ZigBee coordinator or router to directly join a device to its network is initiated by issuing the `NLME-DIRECT-JOIN.request` primitive with the `DeviceAddress` parameter set to the address of the device to be joined to the network. Only those devices that are either a ZigBee coordinator or a ZigBee router may initiate this procedure. If this procedure is initiated on any other device, the NLME may terminate the procedure and notify the next higher layer of the illegal request by issuing the `NLME-DIRECT-JOIN.confirm` primitive with the `Status` parameter set to `INVALID_REQUEST`.

When this procedure is initiated, the NLME of the parent shall first determine whether the specified device already exists on its network. To do this, the NLME shall search its neighbor table in order to determine whether a matching 64-bit, extended address can be found. If a match is found, the NLME shall terminate the procedure and notify the next higher layer that the device is already present in the device list by issuing the `NLME-DIRECT-JOIN.confirm` primitive with the `Status` parameter set to `ALREADY_PRESENT`.

If a match is not found, the NLME shall, if possible, allocate a 16-bit network address for the new device as well as a new neighbor table entry. See sub-clause 3.6.1.6 and sub-clause 3.6.1.7 for an explanation of the address assignment mechanisms. If the parent device has no more room in its neighbor table, the NLME shall terminate the procedure and notify the next higher layer of the

unavailable capacity by issuing the NLME-DIRECT-JOIN.confirm primitive with the Status parameter set to NEIGHBOR_TABLE_FULL. If capacity is available, the NLME shall inform the next higher layer that the device has joined the network by issuing the NLME-DIRECT-JOIN.confirm primitive with the Status parameter set to SUCCESS.

Once the parent has added the child to its network, it is still necessary for the child to make contact with the parent to complete the establishment of the parent-child relationship. The child shall fulfill this requirement by initiating the orphaning procedure, which is described in sub-clause 3.6.1.4.3.1.

A parent that supports direct joining shall follow the procedure illustrated in Figure 3.38 to successfully join a device to the network directly. This procedure does not require any over-the-air transmissions.

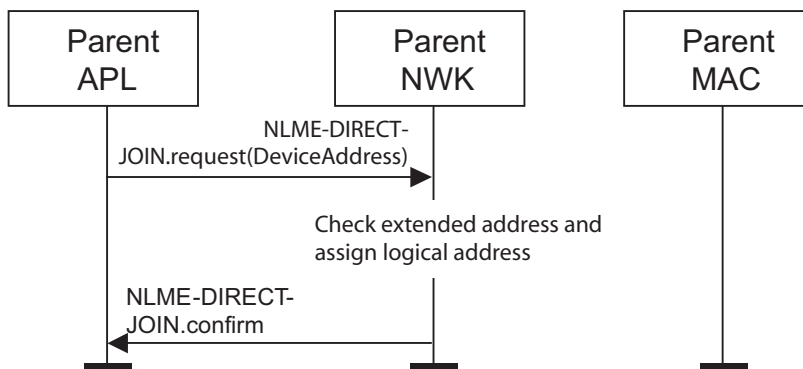


Figure 3.38 Joining a Device to a Network Directly

3.6.1.4.3.1 Joining or Re-joining a Network Through Orphaning

This sub-clause specifies how the orphaning procedure can be initiated by a device that has been directly joined to a network (joining through orphaning) or by a device that was previously joined to a network but has lost contact with its parent (re-joining through orphaning).

A device that has been added to a network directly shall initiate the orphan procedure in order to complete the establishment of its relationship with its parent. The application on the device will determine whether to initiate this procedure and, if so, will notify the network layer upon power up.

A device that was previously joined to a network has the option of initiating the orphan procedure if its NLME repeatedly receives communication failure notifications from its MAC sub-layer.

3.6.1.4.3.2 Child Procedure

The optional joining through orphaning procedure is initiated by a device using the NLME-JOIN.request primitive with the RejoinNetwork parameter set to 0x01.

When this procedure is initiated, the NLME shall first request that the MAC sub-layer perform an orphan scan over the set of channels given by the ScanChannels parameter. An orphan scan is initiated by issuing the MLME-SCAN.request primitive to the MAC sub-layer, and the result is communicated back to the NLME via the MLME-SCAN.confirm primitive.

If the child has found its parent, the orphan scan was successful and the NLME shall inform the next higher layer of the success of its request to join or re-join the network by issuing the NLME-JOIN.confirm primitive with the Status parameter set to SUCCESS.

Note that if the child device is joining for the first time or if the child device has previously been joined to the network, but has failed to retain tree depth information as prescribed in sub-clause 3.6.8, it may not be able to operate correctly on the network without taking measures, outside the scope of this specification, for the recovery of this information.

If the orphan scan was unsuccessful (the parent has not been found), the NLME shall terminate the procedure and notify the next higher layer that no networks were found. This is achieved by issuing the NLME-JOIN.confirm primitive with the Status parameter set to NO_NETWORKS.

The procedure for a child to successfully join or re-join a network through orphaning is illustrated in the MSC shown in Figure 3.39

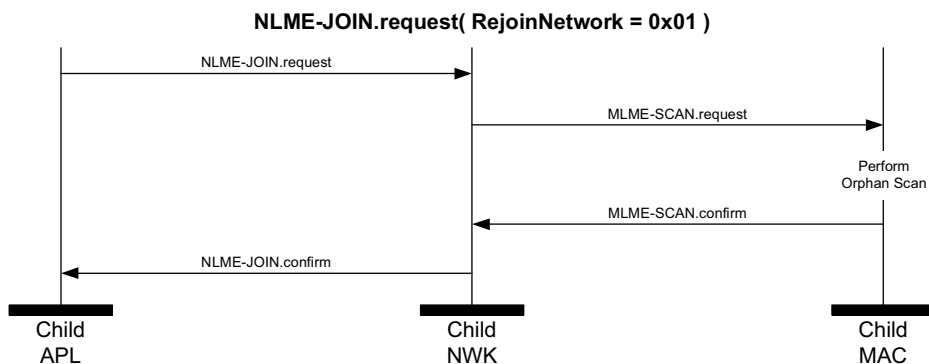


Figure 3.39 Child Procedure for Joining or Re-Joining a Network Through Orphaning

3.6.1.4.3.3 Parent Procedure

A device is notified of the presence of an orphaned device when it receives the MLME-ORPHAN.indication primitive from the MAC sub-layer. Only devices that are either ZigBee coordinators or ZigBee routers (that is, devices with parental capabilities) shall initiate this procedure. If this procedure is initiated by any other device, the NLME shall terminate the procedure.

When this procedure is initiated, the NLME shall first determine whether the orphaned device is its child. This is accomplished by comparing the extended address of the orphaned device with the addresses of its children, as recorded in its neighbor table. If a match is found (the orphaned device is its child), the NLME shall obtain the corresponding 16-bit network address and include it in its subsequent orphan response to the MAC sub-layer. The orphan response to the MAC sub-layer is initiated by issuing the MLME-ORPHAN.response primitive, and the status of the transmission is communicated back to the NLME via the MLME-COMM-STATUS.indication primitive.

If an address match is not found (the orphaned device is not its child), the procedure shall be terminated without indication to the higher layer.

The procedure for a parent to join or re-join its orphaned child to the network is illustrated in the MSC shown in Figure 3.40.

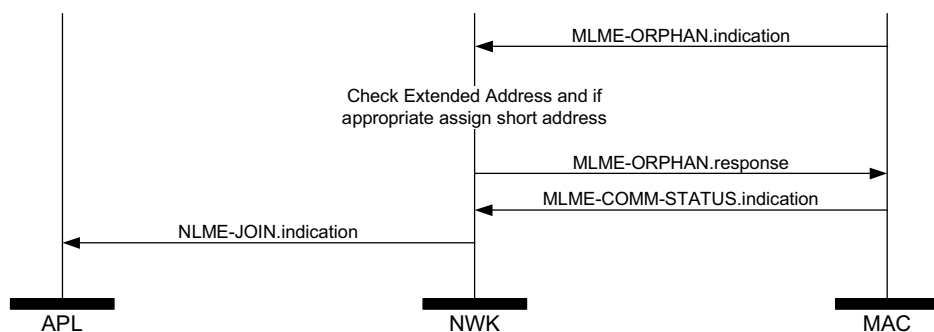


Figure 3.40 Parent Procedure for Joining or Re-Joining a Device to Its Network Through Orphaning

3.6.1.5 Neighbor Tables

The neighbor table of a device shall contain information on every device within transmission range, up to some implementation-dependent limit.

The neighbor table is useful in two contexts. First of all, it is used during network discovery or rejoining to store information about routers within RF reception range that may be candidate parents. Second, after the device has joined a

network, it is used to store relationship and link-state information about neighboring devices in that network. A table entry shall be updated every time a device receives any frame from the corresponding neighbor.

The outgoing cost field contains the cost of the link as measured by the neighbor. The value is obtained from the most recent link status command frame received from the neighbor. A value of 0 indicates that no link status command listing this device has been received.

The age field indicates the number of *nwkLinkStatusPeriod* intervals that have passed since the last link status command frame was received, up to a maximum value of *nwkRouterAgeLimit*.

Mandatory and optional data that are used in normal network operation are listed in Table 3.48.

Table 3.48 Neighbor Table Entry Format

Field Name	Field Type	Valid Range	Description
Extended address	Integer	An extended 64-bit, IEEE address	64-bit IEEE address that is unique to every device. This field shall be present if the neighbor is a parent or child of the device.
Network address	Network address	0x0000 – 0xffff	The 16-bit network address of the neighboring device. This field shall be present in every neighbor table entry.
Device type	Integer	0x00 – 0x02	The type of neighbor device: 0x00 = ZigBee coordinator 0x01 = ZigBee router 0x02 = ZigBee end device This field shall be present in every neighbor table entry.
RxOnWhenIdle	Boolean	TRUE or FALSE	Indicates if neighbor’s receiver is enabled during idle periods: TRUE = Receiver is on FALSE = Receiver is off This field should be present for entries that record the parent or children of a ZigBee router or ZigBee coordinator.

Table 3.48 Neighbor Table Entry Format (Continued)

Field Name	Field Type	Valid Range	Description
Relationship	Integer	0x00 – 0x05	<p>The relationship between the neighbor and the current device:</p> <p>0x00=neighbor is the parent</p> <p>0x01=neighbor is a child</p> <p>0x02=neighbor is a sibling</p> <p>0x03=none of the above</p> <p>0x04=previous child</p> <p>0x05=unauthenticated child</p> <p>This field shall be present in every neighbor table entry.</p>
Transmit Failure	Integer	0x00 – 0xff	<p>A value indicating if previous transmissions to the device were successful or not. Higher values indicate more failures.</p> <p>This field shall be present in every neighbor table entry.</p>
LQI	Integer	0x00 – 0xff	<p>The estimated link quality for RF transmissions from this device. See sub-clause 3.6.3.1 for a discussion of how this is calculated.</p> <p>This field shall be present in every neighbor table entry.</p>
Outgoing Cost	Integer	0x00 - 0xff	<p>The cost of an outgoing link as measured by the neighbor. A value of 0 indicates no outgoing cost is available.</p> <p>This field is mandatory if <i>nwkSymLink</i> = TRUE.</p>

Table 3.48 Neighbor Table Entry Format (Continued)

Field Name	Field Type	Valid Range	Description
Age	Integer	0x00 - 0xff	The number of <i>nwkLinkStatusPeriod</i> intervals since a link status command was received. This field is mandatory if <i>nwkSymLink</i> = TRUE.
Incoming beacon timestamp	Integer	0x000000-0xffffffff	The time, in symbols, at which the last beacon frame was received from the neighbor. This value is equal to the timestamp taken when the beacon frame was received, as described in IEEE 802.15.4-2003 [B1]. This field is optional.
Beacon transmission time offset	Integer	0x000000-0xffffffff	The transmission time difference, in symbols, between the neighbor's beacon and its parent's beacon. This difference may be subtracted from the corresponding incoming beacon timestamp to calculate the beacon transmission time of the neighbor's parent. This field is optional.

Information that may be used during network discovery and rejoining, as described above, is shown in Table 3.49. All of the fields shown are optional and should not be retained after the NLME has chosen a network to join. Neighbor table entries corresponding to devices that are not members of the chosen network should similarly be discarded.

Table 3.49 Additional Neighbor Table Fields

Field Name	Field Type	Valid Range	Description
Extended PAN ID	Integer	0x0000000000000001 - 0xfffffffffffffffe	The 64-bit unique identifier of the network to which the device belongs.
Logical channel	Integer	Selected from the available logical channels supported by the PHY.	The logical channel on which the network is operating.
Depth	Integer	0x00 – 0x0f	The tree depth of the neighbor device.

Table 3.49 Additional Neighbor Table Fields (Continued)

Field Name	Field Type	Valid Range	Description
Beacon order	Integer	0x00 – 0x0f	The IEEE 802.15.4 beacon order for the device.
Permit joining	Boolean	TRUE or FALSE	An indication of whether the device is accepting joining requests. TRUE = device is accepting join requests. FALSE = device is not accepting join requests.
Potential parent	Integer	0x00 – 0x01	An indication of whether the device has been ruled out as a potential parent. 0x00 indicates that the device is not a potential parent. 0x01 indicates that the device is a potential parent.

3.6.1.6 Distributed Address Assignment Mechanism

The default value of the NIB attribute *nwkAddrAlloc* is 0x00, where network addresses are assigned using a distributed addressing scheme that is designed to provide every potential parent with a finite sub-block of network addresses. These addresses are unique within a particular network and are given by a parent to its children. The ZigBee coordinator determines the maximum number of children any device, within its network, is allowed. Of these children, a maximum of *nwkMaxRouters* can be router-capable devices. The remaining devices shall be reserved for end devices. Every device has an associated depth that indicates the minimum number of hops a transmitted frame must travel, using only parent-child links, to reach the ZigBee coordinator. The ZigBee coordinator itself has a depth of 0, while its children have a depth of 1. Multi-hop networks have a maximum depth that is greater than 1. The ZigBee coordinator also determines the maximum depth of the network.

Given values for the maximum number of children a parent may have, *nwkMaxChildren* (*C_m*), the maximum depth in the network, *nwkMaxDepth* (*L_m*), and the maximum number of routers a parent may have as children, *nwkMaxRouters* (*R_m*), we may compute the function, *Cskip(d)*, essentially the size of the address sub-block being distributed by each parent at that depth to its

router-capable child devices for a given network depth, d , as follows:

$$Cskip(d) = \begin{cases} 1 + Cm \cdot (Lm - d - 1), & \text{if } Rm = 1 \\ \frac{1 + Cm - Rm - Cm * Rm^{Lm-d-1}}{1 - Rm}, & \text{otherwise} \end{cases}$$

If a device has a $Cskip(d)$ value of 0, then it shall not be capable of accepting children and shall be treated as a ZigBee end device for purposes of this discussion. The NLME of the device shall set the End device Capacity and Router Capacity sub fields of the MAC sub-layer beacon payload to 0.

A parent device that has a $Cskip(d)$ value greater than 0 shall accept child devices and shall assign addresses to them differently depending on whether or not the child device is router-capable.

Network addresses shall be assigned to router-capable child devices using the value of $Cskip(d)$ as an offset. A parent assigns an address that is 1 greater than its own to its first router-capable child device. Subsequently assigned addresses to router-capable child devices are separated from each other by $Cskip(d)$. A maximum of $nwkMaxRouters$ of such addresses shall be assigned.

Network addresses shall be assigned to end devices in a sequential manner with the n^{th} address, A_n , given by the following equation:

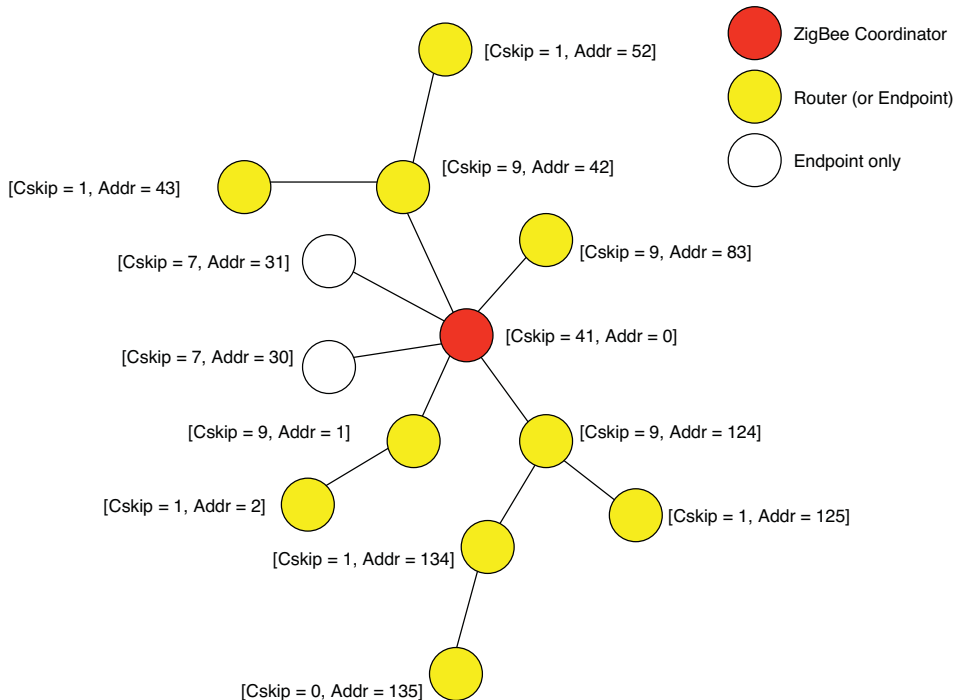
$$A_n = A_{parent} + Cskip(d) * Rm + n$$

Where $d(1 \leq n \leq (Cm - Rm))$ and A_{parent} represents the address of the parent.

The $Cskip(d)$ values for an example network having $nwkMaxChildren=6$, $nwkMaxRouters=4$ and $nwkMaxDepth=3$ are calculated and listed in Table 3.50. Figure 3.41 illustrates the example network.

Table 3.50 Example Addressing Offset Values for Each Given Depth Within the Network

Depth in the Network, d	Offset Value, $Cskip(d)$
d of 0	Change $Cskip(d)$ to 31
d of 1	Change $Cskip(d)$ to 9
d of 2	Leave $Cskip(d)$ as 1
d of 3	Leave $Cskip(d)$ as 0



Note: Can't use same Rm, Cm and Lm as spec. as this does not yield 'endpoint only' addresses. Changed to Cm = 6 (from 4), Lm = 3, Rm = 4. This allows two extra 'endpoint only' devices to be shown at depth 1.

Figure 3.41 Address Assignment in an Example Network

Because an address sub-block cannot be shared between devices, it is possible that one parent exhausts its list of addresses while a second parent has addresses that go unused. A parent having no available addresses shall not permit a new device to join the network by setting the End Device Capacity and Router Capacity sub fields of the MAC sub-layer beacon payload to 0.

In this situation, the new device shall find another parent. If no other parent is available within transmission range of the new device, the device shall be unable to join the network unless it is physically moved or there is some other change.

3.6.1.7 Stochastic Address Assignment Mechanism

When the NIB attribute *nwkAddrAlloc* has value 0x02, addresses shall be chosen at random. The value of *nwkMaxRouter* is not relevant in this case. The random address assigned shall conform to the NIST testing regimen described in reference [B12]. When a device joins the network using MAC association, its parent shall choose a random address that does not already appear in any entry in the parent's NIB. Under stochastic addressing, once a device has been assigned an address, it

has no reason to relinquish that address and should retain it unless it receives an indication that its address is in conflict with that of another device on the network. Furthermore, devices may self-assign random addresses under stochastic addressing and retain them, as in the case of joining a network using the rejoin command frame (see sub-clause 3.6.1.4.2). The ZigBee coordinator, which has no parent, shall always have the address 0x0000.

3.6.1.8 Installation and Addressing

It should be clear that *nwkMaxDepth* roughly determines the number of hops in network terms from the root of the tree to the farthest end device. In principle, *nwkMaxDepth* also determines the overall network diameter. In particular, for an ideal network layout in which the ZigBee coordinator is located in the center of the network, as illustrated in Figure 3.41, the network diameter should be $2 * nwkMaxDepth$. In practice, application-driven placement decisions and order of deployment may lead to a smaller diameter. In this case, *nwkMaxDepth* provides a lower bound on the network diameter while the $2 * nwkMaxDepth$ provides the upper bound.

Finally, due to the fact that the tree is not dynamically balanced, when *nwkAddrAlloc* has a value of 0x00, the possibility exists that certain installation scenarios, such as long lines of devices, may exhaust the address capacity of the network long before the real capacity is reached.

Under stochastic address assignment, *nwkMaxDepth* is related to the number of hops across the network. This is not a controlled value in networks using stochastic address assignment.

3.6.1.9 Address Conflicts

An address conflict occurs when two devices in the same network have identical values for *nwkNetworkAddress*. Preventing all such conflicts, for example by using tree address assignment and prohibiting the reuse of assigned addresses, is not always practical. This section describes how address conflicts that do occur can be detected and corrected. Address conflict detection shall be enabled if the NIB attribute *nwkUniqueAddr* is FALSE.

Note that the network addresses used in routing messages are verified during the route discovery process. The device_annnc now is also used to verify addresses. The verification applies only to devices, links, and information present at the time of the discovery or device_annnc. Verification can be achieved at other times, such as before sending a unicast directly to a neighbor, by sending a network status command with a status code value of 0x00e, indicating address verification.

If a device receives a broadcast data frame and discovers an address conflict as a result of the receipt, as discussed below in sub-clause 3.6.1.9.2, it should not

retransmit the frame as usual but shall discard it before taking the resolution actions described below in sub-clause 3.6.1.9.3.

3.6.1.9.1 Obtaining Address Information

The NWK layer obtains address information from incoming messages, including both NWK commands and data messages. Address information from data messages is passed to the NWK layer by being added to the network address map table in the NIB.

The ability to detect address conflicts is enhanced by adding one or both of the Destination IEEE Address and Source IEEE Address fields to a message's NWK frame. When *nwkUniqueAddr* is FALSE, all NWK command messages shall contain the source IEEE address and also the destination IEEE address if it is known by the source device.

When *nwkUniqueAddr* is FALSE, route request commands shall include the sender's IEEE address in the Sender IEEE address field. This ensures that devices are aware of their neighbors' IEEE addresses.

3.6.1.9.2 Detecting Address Conflicts

After joining a network or changing address due to a conflict, a device shall send either a device_annnc or initiate a route discovery prior to sending messages.

Upon receipt of a frame containing a 64-bit IEEE address in the NWK header, the contents of the *nwkAddressMap* attribute of the NIB and neighbor table should be checked for consistency.

If the destination address field of the NWK Header of the incoming frame is equal to the *nwkNetworkAddress* attribute of the NIB then the NWK layer shall check the destination IEEE address field, if present, against the value of *aExtendedAddress*. If the IEEE addresses are not identical then a local address conflict has been detected on *nwkNetworkAddress*.

If a neighbor table or address map entry is located in which the 64-bit address is the null IEEE address (0x00....00), the 64-bit address in the table can be updated. However, if the 64-bit address is not the null IEEE address and does not correspond to the received 16-bit address, the device has detected a conflict elsewhere in the network.

When a broadcast frame is received that creates a new BTR, if the Source Address field in the NWK Header is equal to the *nwkNetworkAddress* attribute of the NIB then a local address conflict has been detected on *nwkNetworkAddress*.

Address conflicts are resolved as described in sub-clause 3.6.1.9.3.

3.6.1.9.3 Resolving Address Conflicts

If a ZigBee coordinator or Router determines that there are multiple users of an address that is not its own, it shall inform the network by broadcasting a network

status command with a status code of 0x0d indicating address conflict, and with the offending address in the destination address field. The network status command shall be broadcast to 0xFFFFD, i.e. all devices with *macRxOnWhenIdle* = TRUE. The device shall delay initiation of this broadcast by a random jitter amount bounded by *nwkMaxBroadcastJitter*. If during this delay a network status is received with the identical payload, the device shall cancel its own broadcast.

If the device has learned of the conflict other than receiving a network status command with a status of 0x0d, then it shall inform the network by broadcasting a network status command with a status code of 0x0d indicating address conflict, and with its previous address in the destination address field. The network status command shall be broadcast to 0xFFFFD, i.e. all devices with *macRxOnWhenIdle* = TRUE. The device shall delay initiation of this broadcast by a random jitter amount bounded by *nwkMaxBroadcastJitter*. If during this delay a network status is received with the identical payload, the device shall cancel its own broadcast. Regardless of how it learned of the conflict, it shall implement the procedure on Detecting Address Conflicts detailed in sub-clause 3.6.1.9.2.

If the conflict is detected on a ZigBee end device or *nwkAddrAlloc* is not equal to stochastic address assignment then the device shall perform a rejoin to obtain a new address. Otherwise, the device that requires a new address shall pick a new address randomly, avoiding all addresses that appear in NIB entries.

If a parent device detects or is informed of a conflict with the address of an end device child, the parent shall pick a new address for the end device child and shall send an unsolicited rejoin response command frame to inform the end device child of the new address. To notify the next higher layer of an address change the end device shall issue an NLME-NWK-STATUS.indication with status 'Network Address Update' and the new network address as the value of the ShortAddr parameter.

3.6.1.10 Leaving a Network

This sub-clause specifies methods for a device to remove itself from the network and for the parent of a device to request its removal. In both cases, the children of the removed device, if any, may also be removed.

3.6.1.10.1 Method for a Device to Initiate Its Own Removal from the Network

This sub-clause describes how a device can initiate its own removal from the network in response to the receipt of an NLME-LEAVE.request primitive from the next higher layer as shown in Figure 3.42.

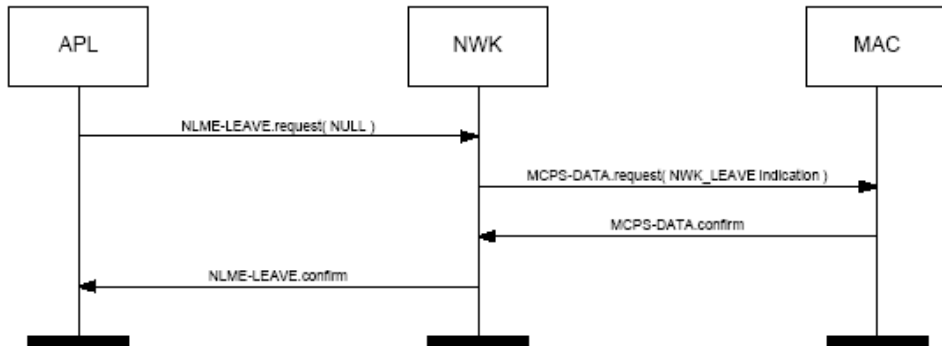


Figure 3.42 Initiation of the Leave Procedure

When the NWK layer of a ZigBee router or ZigBee coordinator, receives the `NLME-LEAVE.request` primitive with the `DeviceAddress` parameter equal to `NULL` (indicating that the device is to remove itself) the device shall send a leave command frame using the `MCPS-DATA.request` primitive with the `DstAddr` parameter set to `0xffff` indicating a MAC broadcast. The request sub-field of the command options field of the leave command frame shall be set to 0. The value of the remove children sub-field of the command options field of the leave command shall reflect the value of the `RemoveChildren` parameter of the `NLME-LEAVE.request` primitive, and the value of the `Rejoin` sub-field of the leave command shall reflect the value of the `Rejoin` parameter of the `NLME-LEAVE.request` primitive. After transmission of the leave command frame, it shall issue a `NLME-LEAVE.confirm` primitive to the higher layer with the `DeviceAddress` parameter equal to `NULL`. The `Status` parameter shall be `SUCCESS` if the leave command frame was transmitted successfully. Otherwise, the `Status` parameter of the `NLME-LEAVE.confirm` shall have the same value as the `Status` parameter returned by the `MCPS-DATA.confirm` primitive.

If the device receiving the `NLME-LEAVE.request` primitive is a ZigBee end device, then the device shall send a leave command frame using the `MCPS-DATA.request` primitive with the `DstAddr` parameter set to the 16-bit network address of its parent device, indicating a MAC unicast. The request and remove children sub-fields of the command options field of the leave command frame shall be set to 0. After transmission of the leave command frame, it shall set the *nwkExtendedPANId* attribute of the NIB to `0x0000000000000000` and issue a `NLME-LEAVE.confirm` primitive to the higher layer with the `DeviceAddress` parameter equal to `NULL`. The `Status` parameter shall be `SUCCESS` if the leave command frame was transmitted successfully. Otherwise, the `Status` parameter of the `NLME-LEAVE.confirm` shall have the same value as the `Status` parameter returned by the `MCPS-DATA.confirm` primitive.

3.6.1.10.2 Method for a Device to Remove Its Child from the Network

This sub-clause describes how a device can initiate the removal from the network of one of its child devices in response to the receipt of an NLME-LEAVE.request primitive from the next higher layer as shown in Figure 3.43.

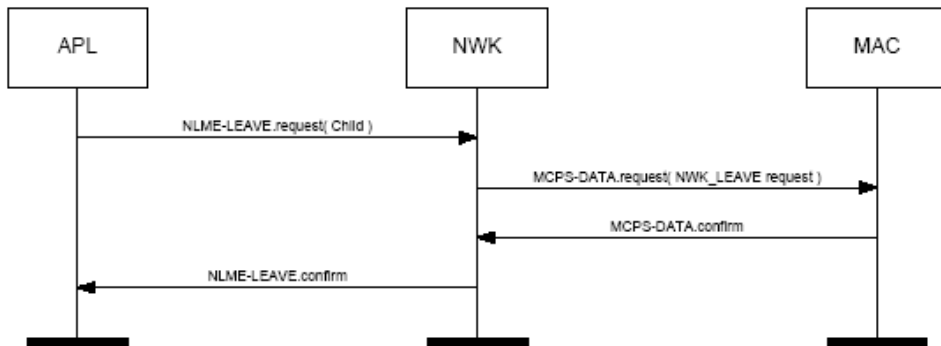


Figure 3.43 Procedure for a Device to Remove Its Child

When the NWK layer of a ZigBee coordinator or ZigBee router, receives the NLME-LEAVE.request primitive with the DeviceAddress parameter equal to the 64-bit IEEE address of a child device, if the relationship field of the neighbor table entry corresponding to that child device does not have a value of 0x05 indicating that the child has not yet authenticated, the device shall send a network leave command frame using the MCPS-DATA.request primitive with the DstAddr parameter set to the 16-bit network address of that child device. The request sub-field of the command options field of the leave command frame shall have a value of 1, indicating a request to leave the network. The value of the remove children sub-field of the command options field of the leave command shall reflect the value of the RemoveChildren parameter of the NLME-LEAVE.request primitive, and the value of the Rejoin sub-field of the leave command shall reflect the value of the Rejoin parameter of the NLME-LEAVE.request primitive.

If the relationship field of the neighbor table entry corresponding to the device being removed has a value of 0x05, indicating that it is an unauthenticated child, the device shall not send a network leave command frame.

Next, the NWK layer shall issue the NLME-LEAVE.confirm primitive with the DeviceAddress parameter set to the 64-bit IEEE address of the child device being removed. The Status parameter of the NLME-LEAVE.confirm primitive shall have a value of SUCCESS if the leave command frame was not transmitted, *i.e.* in the case of an unauthenticated child. Otherwise, the Status parameter of the NLME-LEAVE.confirm shall have the same value as the Status parameter returned by the MCPS-DATA.confirm primitive.

After the child device has been removed, the NWK layer of the parent should modify its neighbor table, and any other internal data structures that refer to the child device, to indicate that the device is no longer on the network. It is an error for the next higher layer to address and transmit frames to a child device after that device has been removed.

If an unauthenticated child device is removed from the network before it is authenticated, then the address formerly in use by the device being asked to leave may be assigned to another device that joins subsequently.

ZigBee end devices have no child devices to remove and should not receive NLME-LEAVE.request primitives with non-NULL DeviceAddress parameters.

3.6.1.10.3 Upon Receipt of the Leave Command Frame

Upon receipt of the leave command frame by the NWK layer via the MCPS-DATA.indication primitive, as shown in Figure 3.44, the device shall check the value of the request sub-field of the command options field of the command frame. If the request sub-field has a value of 0, then the NWK layer shall issue the NLME-LEAVE.indication primitive to the next higher layer with the device address parameter equal to the value in the source IEEE Address sub-field of the leave command frame. The device should also modify its neighbor table, and any other internal data structures that refer to the leaving device, to indicate that the leaving device²³ is no longer on the network. It is an error for the next higher layer to address and transmit frames to a device after that device has left the network.

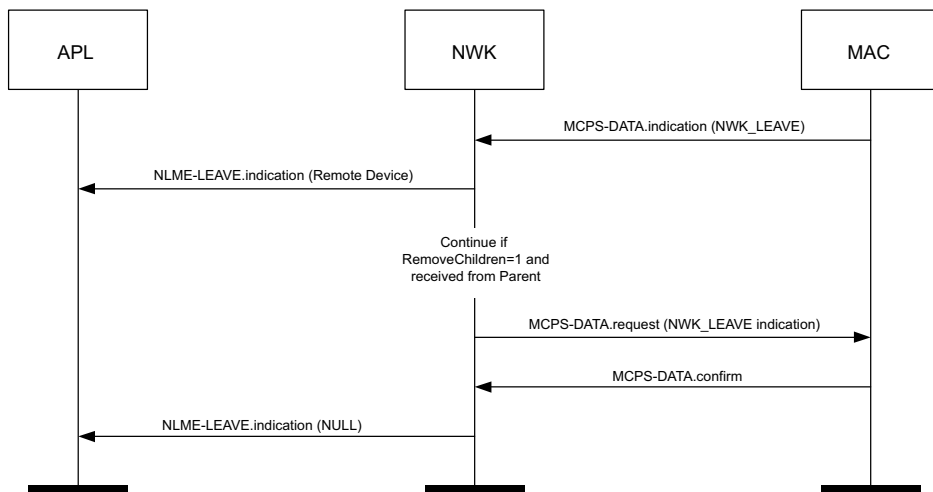


Figure 3.44 On Receipt of a Leave Command

23. CCB 1279

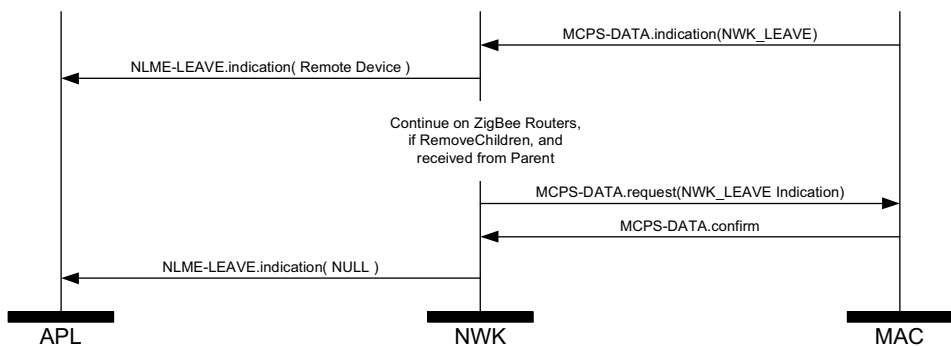


Figure 3.45 On Receipt of a Leave Command by a ZED

If, on receipt by the NWK layer of a ZigBee router of a leave command frame as described above, the `SrcAddr` parameter of the `MCPS-DATA.indication` that delivered the command frame is the 16-bit network address of the parent of the recipient, and either the value of the request sub-field of the command options field is found to have a value of 1 or the value of the remove children sub-field of the command options field is found to have a value of 1, then the recipient shall send a leave command frame using the `MCPS-DATA.request` primitive with the `DstAddr` parameter set to 0xffff indicating a MAC broadcast. The request sub-field of the command options field of the leave command frame shall be set to 0.

The value of the remove children sub-field of the command options field of the outgoing leave command shall reflect the value of the same field for the incoming leave command frame. After transmission of the leave command frame, it shall set the `nwkExtendedPANId` attribute of the NIB to 0x0000000000000000 and it shall issue a `NLME-LEAVE.indication` primitive to the higher layer with `DeviceAddress` parameter equal to `NULL`.

If the request sub-field has a value of 1, the device is an end device and the source of the leave command frame is a device other than the parent of the recipient, the frame shall be immediately and silently discarded; the device shall not leave the network. If the request sub-field has a value of 1, the `nwkLeaveRequestAllowed` attribute of the NIB (Table 3.44) is `FALSE`, and the device is not an end device, the frame shall be immediately and silently discarded; the device shall not leave the network.²⁴

If a ZigBee end device receives a leave command frame as described above and the `SrcAddr` parameter of the `MCPS-DATA.indication` that delivered the command frame is the 16-bit network address of the parent of the recipient, it shall set the `nwkExtendedPANId` attribute of the NIB to 0x0000000000000000 and

24. CCB 1279

shall issue a NLME-LEAVE.indication primitive to the higher layer with DeviceAddress parameter equal to NULL.

The NWK layer may employ retry techniques, as described in sub-clause 3.6.5 to enhance the reliability of the leave procedure but, beyond this note, these mechanisms are outside the scope of this specification.

3.6.1.11 Changing the ZigBee Coordinator Configuration

If the next higher layer of a ZigBee coordinator device wishes to change the configuration of the network, it shall request that the MAC sub-layer instigate the changes in its PIB. The ZigBee coordinator configuration is composed of the following items:

- Whether or not the device wishes to be a ZigBee parent
- The beacon order of the MAC superframe
- The superframe order of the MAC superframe
- Whether or not battery life extension mode is to be used

A change to the ZigBee coordinator configuration is initiated by issuing the NLME-NETWORK-FORMATION.request primitive to the NLME. The status of the attempt is communicated back via the NLME-NETWORK-FORMATION.confirm primitive.

For more details on the impact of such changes imposed on the MAC sub-layer see IEEE 802.15.4-2003 [B1].

3.6.1.12 Resetting a Device

The NWK layer of a device shall be reset immediately following initial power-up, before a join attempt to a new network and after a leave attempt where the device is not intending to rejoin the network. This process should not be initiated at any other time. A reset is initiated by issuing the NLME-RESET.request primitive to the NLME and the status of the attempt is communicated back via the NLME-RESET.confirm primitive. The reset process shall clear the routing table entries of the device.

Some devices may store NWK layer quantities in non-volatile memory and restore them after a reset. The WarmStart parameter of the NLME-RESET.request may also be used for this purpose. When *nwkAddrAlloc* is equal to 0x00, a device always gets a network address from its parent upon joining or rejoining. The new network address may be different from its old network address. In such a case, any device that is communicating with the device that has been reset must rediscover the device using higher-layer protocols. When *nwkAddrAlloc* is equal to 0x02, a device may use the same address on rejoining a network and therefore should not discard its address on reset unless it does not intend to rejoin the same network.

3.6.1.13 Managing a PANId Conflict

Since the 16-bit PANID is not a unique number there is a possibility of a PANID conflict. The next section explains how — through the use of the Network Report and Network Update command frames — the PANID of a network can be updated.

3.6.1.13.1 Detecting a PANId Conflict

Any device that is operational on a network and receives an MLME-BEACON-NOTIFY.indication in which the PAN identifier of the beacon frame matches its own PAN identifier but the EPID value contained in the beacon payload is either not present or not equal to *nwkExtendedPANID*, shall be considered to have detected a PAN Identifier conflict.

A node that has detected a PAN identifier conflict shall construct a Network Report Command frame of type PAN Identifier Conflict which shall be sent to the device identified by the address given in the *nwkManagerAddr* attribute of the NIB. The Report Information field will contain a list of all the 16-bit PAN identifiers that are being used in the local neighborhood. How this list is created is outside the scope of the specification, however it is recommended that it be constructed from the results of an MLME-SCAN.request of type ACTIVE.

3.6.1.13.2 Upon Receipt of a Network Report Command Frame

The device identified by the 16-bit network address contained within the *nwkManagerAddr* attribute of the NIB shall be the recipient of network report command frames of type PAN identifier conflict.

On receipt of the network report command frame, the designated network layer function manager shall select a new 16-bit PAN identifier for the network. The new PAN identifier is chosen at random, but a check is performed to ensure that the chosen PAN identifier is not already in use in the local neighborhood and also not contained within the Report Information field of the network report command frame.

Once a new PAN identifier has been selected, the designated network layer function manager shall first increment the NIB attribute *nwkUpdateId* (wrapping around to 0 if necessary) and then shall construct a network update command frame of type PAN identifier update. The update information field shall be set to the value of the new PAN identifier. The network update command frame shall be sent to the ZigBee coordinator.

After it sends out this command frame, the designated network layer function manager shall start a timer with a value equal to *nwkNetworkBroadcastDeliveryTime* OctetDurations.²⁵ When the timer expires,

25. ZigBee Document 12-0220-04

the ZigBee coordinator shall change its current PAN ID to the newly selected one by reissuing the MLME-START.request with the new PANID.

Upon transmission of the Network Update command frame the designated network layer function manager shall create a NLME-NWK-STATUS.indication primitive with the NetworkAddr parameter set to 0 and the Status parameter set to PAN Identifier Update.

3.6.1.13.3 Upon Receipt of a Network Update Command Frame

On receipt of a network update command frame of type PAN identifier update, a device shall start a timer with a value equal to *nwkNetworkBroadcastDeliveryTime* OctetDurations.²⁶ When the timer expires, the device shall change its current PAN Identifier to the value contained within the Update Information field.

Upon transmission of the network update command frame the device shall create a NLME-NWK-STATUS.indication primitive with the NetworkAddr parameter set to 0 and the Status parameter set to PAN Identifier Update.

Upon receipt of the Network Update command from the device identified by the *nwkManagerAddr* attribute of the NIB, the value contained in the update id field shall be stored in *nwkUpdateId* attribute in the NIB. The beacon payload shall also be updated.

3.6.2 Transmission and Reception

3.6.2.1 Transmission

Only those devices that are currently associated shall send data frames from the NWK layer. If a device that is not associated receives a request to transmit a frame, it shall discard the frame and notify the higher layer of the error by issuing an NLDE-DATA.confirm primitive with a status of INVALID_REQUEST.

All frames handled by or generated within the NWK layer shall be constructed according to the general frame format specified in Figure 3.5 and transmitted using the MAC sub-layer data service.

In addition to source address and destination address fields, all NWK layer transmissions shall include a radius field and a sequence number field. For data frames originating at a higher layer, the value of the radius field may be supplied using the Radius parameter of the NLDE-DATA.request primitive. If a value is not supplied, then the radius field of the NWK header shall be set to twice the value of the *nwkMaxDepth* attribute of the NIB (see clause 3.5). The NWK layer on every device shall maintain a sequence number that is initialized with a random

26. ZigBee Document 12-0220-04

value. The sequence number shall be incremented by 1, each time the NWK layer constructs a new NWK frame, either as a result of a request from the next higher layer to transmit a new NWK data frame or when it needs to construct a new NWK layer command frame. After being incremented, the value of the sequence number shall be inserted into the sequence number field of the frame's NWK header.

Once an NPDU is complete, if security is required for the frame, it shall be passed to the security service provider for subsequent processing according to the specified security suite (see sub-clause 4.2.2). Security processing is not required if the SecurityEnable parameter of the NLDE-DATA.request is equal to FALSE. If the NWK security level as specified in *nwkSecurityLevel* is equal to 0, or if the frame originated at the higher layer and the *nwkSecureAllFrames* NIB attribute is set to 0x00, then the security sub-field of the frame control field shall always be set to 0.

On successful completion of the secure processing, the security suite returns the frame to the NWK layer for transmission. The processed frame will have the correct auxiliary header attached. If security processing of the frame fails and the frame was a data frame, the frame will inform the higher layer of the NLDE-DATA.confirm primitive's status. If security processing of the frame fails and the frame is a network command frame, it is discarded and no further processing shall take place.

When the frame is constructed and ready for transmission, it shall be passed to the MAC data service. An NPDU transmission is initiated by issuing the MCPS-DATA.request primitive to the MAC sub-layer. The MCPS-DATA.confirm primitive then returns the results of the transmission.

3.6.2.2 Reception and Rejection

In order to receive data, a device must enable its receiver. The next higher layer may initiate reception using the NLME-SYNC.request primitive. On a beacon-enabled network, receipt of this primitive by the NWK layer shall cause a device to synchronize with its parent's next beacon and, optionally, to track future beacons. The NWK layer shall accomplish this by issuing an MLME-SYNC.request to the MAC sub-layer. On a non-beacon-enabled network, the NLME-SYNC.request shall cause the NWK layer of a device with *macRxOnWhenIdle* set to FALSE to poll the device's parent using the MLME-POLL.request primitive.

On a non-beacon-enabled network, the NWK layer on a ZigBee coordinator or ZigBee router shall ensure, to the maximum extent feasible, that the receiver is enabled whenever the device is not transmitting. On a beacon-enabled network, the NWK layer should ensure that the receiver is enabled when the device is not transmitting during the active period of its own superframe and of its parent's

superframe. The NWK layer may use the *macRxOnWhenIdle* attribute of the MAC PIB for this purpose.

Once the receiver is enabled, the NWK layer will begin to receive frames via the MAC data service. On receipt of each frame, the radius field of the NWK header shall be decremented by 1. If, as a result of being decremented, this value falls to 0, the frame shall not, under any circumstances, be retransmitted. It may, however, be passed to the next higher layer or otherwise processed by the NWK layer as outlined elsewhere in this specification. The following data frames shall be passed to the next higher layer using the NLDE-DATA.indication primitive:

- Frames with a broadcast address that matches a broadcast group of which the device is a member.
- Unicast data frames and source-addressed data frames for which the destination address matches the device's network address.
- Multicast data frames whose group identifier is listed in the *nwkGroupIDTable*.

If the receiving device is a ZigBee coordinator or an operating ZigBee router, that is, a router that has already invoked the NLME-START-ROUTER.request primitive, it shall process data frames as follows:

- Broadcast and multicast data frames shall be relayed according to the procedures outlined in sub-clauses 3.6.5 and 3.6.6.
- Unicast data frames with a destination address that does not match the device's network address shall be relayed according to the procedures outlined in sub-clause 3.6.3.3. (Under all other circumstances, unicast data frames shall be discarded immediately.)
- Source-routed data frames with a destination address that does not match the device's network address shall be relayed according to the procedures outlined in sub-clause 3.6.3.3.2.
- The procedure for handling route request command frames is outlined in sub-clause 3.6.3.5.2.
- The procedure for handling route reply command frames for which the destination address matches the device's network address is outlined in sub-clause 3.6.3.5.3.
- Route reply command frames for which the destination address does not match the device's network address shall be discarded immediately. Network status command frames shall be handled in the same manner as data frames.

The NWK layer shall indicate the receipt of a data frame to the next higher layer using the NLDE-DATA.indication primitive.

On receipt of a frame, the NLDE shall check the value of the security sub-field of the frame control field. If this value is non-zero, the NLDE shall pass the frame to

the security service provider (see 4.2.2) for subsequent processing according to the specified security suite. If the security sub-field is set to 0, the *nwkSecurityLevel* attribute in the NIB is non-zero, and the incoming frame is a NWK command frame, the NLDE shall discard the frame. If the security sub-field is set to 0, the *nwkSecurityLevel* attribute in the NIB is non-zero, and the incoming frame is a NWK data frame, the NLDE shall check the *nwkSecureAllFrames* NIB attribute. If this attribute is set to 0x01, the NLDE shall only accept the frame if it is destined to itself, that is, if it does not need to be forwarded to another device.

3.6.3 Routing

ZigBee coordinators and routers shall provide the following functionality:

- Relay data frames on behalf of higher layers
- Relay data frames on behalf of other ZigBee routers
- Participate in route discovery in order to establish routes for subsequent data frames
- Participate in route discovery on behalf of end devices
- Participate in route repair
- Employ the ZigBee path cost metric as specified in route discovery

ZigBee coordinators or routers may provide the following functionality:

- Maintain routing tables in order to remember best available routes
- Initiate route discovery on behalf of higher layers
- Initiate route discovery on behalf of other ZigBee routers
- Initiate route repair
- Conduct neighbor routing

3.6.3.1 Routing Cost

The ZigBee routing algorithm uses a path cost metric for route comparison during route discovery and maintenance. In order to compute this metric, a cost, known as the link cost, is associated with each link in the path and link cost values are summed to produce the cost for the path as a whole.

More formally, if we define a path P of length L as an ordered set of

devices $[D_1, D_2, \dots, D_L]$ and a link, $[D_i, D_{i+1}]$ as a sub-path of length 2, then the path cost

$$C\{P\} = \sum_{i=1}^{L-1} C\{[D_i, D_{i+1}]\}$$

where each of the values $C\{[D_i, D_{i+1}]\}$ is referred to as a link cost. The link cost $C\{l\}$ for a link l is a function with values in the interval $[0...7]$ defined as:

$$C\{l\} = \begin{cases} 7, \\ \min\left(7, \text{round}\left(\frac{1}{p_l^4}\right)\right) \end{cases}$$

where p_l is defined as the probability of packet delivery on the link l .

Thus, implementers may report a constant value of 7 for link cost or they may report a value that reflects the probability p_l of reception — specifically, the reciprocal of that probability — which should, in turn, reflect the number of expected attempts required to get a packet through on that link each time it is used. A device that offers both options may be forced to report a constant link cost by setting the value of the NIB attribute *nwkReportConstantCost* to TRUE. If the *nwkSymLink* attribute of the NIB has a value of TRUE, then the *nwkReportConstantCost* attribute must have a value of FALSE, and the NWK layer must calculate routing cost in the manner described above.

The question that remains, however, is how p_l is to be estimated or measured. This is primarily an implementation issue, and implementers are free to apply their ingenuity. p_l may be estimated over time by actually counting received beacon and data frames and observing the appropriate sequence numbers to detect lost frames. This is generally regarded as the most accurate measure of reception probability. However, the most straightforward method, available to all, is to form estimates based on an average over the per-frame LQI value provided by the IEEE 802.15.4-2003 MAC and PHY. Even if some other method is used, the initial cost estimates shall be based on average LQI. A table-driven function may be used to map average LQI values onto $C\{l\}$ values. It is strongly recommended that implementers check their tables against data derived from tests performed on production hardware, as inaccurate costs will hamper the operating ability of the ZigBee routing algorithm.

3.6.3.2 Routing Tables

A ZigBee router or ZigBee coordinator may maintain a routing table. The information that shall be stored in a ZigBee routing table entry is shown in Table 3.51. The aging and retirement of routing table entries in order to reclaim

table space from entries that are no longer in use is a recommended practice; it is, however, out of scope of this specification.

Table 3.51 Routing Table Entry

Field Name	Size	Description
Destination address	2 octets	The 16-bit network address or Group ID of this route. If the destination device is a ZigBee router, ZigBee coordinator, or an end device, and <i>nwkAddrAlloc</i> has a value of 0x02, this field shall contain the actual 16-bit address of that device. If the destination device is an end device and <i>nwkAddrAlloc</i> has a value of 0x00, this field shall contain the 16-bit network address of the device’s parent.
Status	3 bits	The status of the route. See Table 3.52 for values.
No route cache	1 bit	A flag indicating that the destination indicated by this address does not store source routes.
Many-to-one	1 bit	A flag indicating that the destination is a concentrator that issued a many-to-one route request.
Route record required	1 bit	A flag indicating that a route record command frame should be sent to the destination prior to the next data packet.
GroupID flag	1 bit	A flag indicating that the destination address is a Group ID.
Next-hop address	2 octets	The 16-bit network address of the next hop on the way to the destination.

Table 3.52 enumerates the values for the route status field.

Table 3.52 Route Status Values

Numeric Value	Status
0x0	ACTIVE
0x1	DISCOVERY_UNDERWAY
0x2	DISCOVERY_FAILED
0x3	INACTIVE
0x4	VALIDATION_UNDERWAY
0x5 – 0x7	Reserved

This section describes the routing algorithm. The term “routing table capacity” is used to describe a situation in which a device has the ability to use its routing table to establish a route to a particular destination device. A device is said to have routing table capacity if:

- It is a ZigBee coordinator or ZigBee router
- It maintains a routing table

- It has a free routing table entry or it already has a routing table entry corresponding to the destination

If a ZigBee router or ZigBee coordinator maintains a routing table, it shall also maintain a route discovery table containing the information shown in Table 3.53. Routing table entries are long-lived, while route discovery table entries last only as long as the duration of a single route discovery operation and may be reused.

Table 3.53 Route Discovery Table Entry

Field Name	Size	Description
Route request ID	1 octet	A sequence number for a route request command frame that is incremented each time a device initiates a route request.
Source address	2 octets	The 16-bit network address of the route request's initiator.
Sender address	2 octets	The 16-bit network address of the device that has sent the most recent lowest cost route request command frame corresponding to this entry's route request identifier and source address. This field is used to determine the path that an eventual route reply command frame should follow.
Forward cost	1 octet	The accumulated path cost from the source of the route request to the current device.
Residual cost	1 octet	The accumulated path cost from the current device to the destination device.
Expiration time	2 octets	A countdown timer indicating the number of milliseconds until route discovery expires. The initial value is <i>nwkcRouteDiscoveryTime</i> .

A device is said to have “route discovery table capacity” if:

- It maintains a route discovery table
- It has a free entry in its route discovery table

If a device has both routing table capacity and route discovery table capacity then it may be said to have “routing capacity.”

During route discovery, the information that a ZigBee router or ZigBee coordinator is required to maintain in order participate in the discovery of a particular route is distributed between a routing table entry and a route discovery table entry. Once discovery has been completed, only the routing table entry need be maintained in order for the NWK layer to perform routing along the discovered route. Throughout this sub-clause, references are made to this relationship between a routing table entry and its “corresponding” route discovery table entry and vice versa. The maintenance of this correspondence is up to the implementer since entries in the tables have no elements in common, but it is worth noting in this regard that the unique “keys” that define a route discovery are the source

address of the route discovery command frame and the route request ID generated by that device and carried in the command frame payload.

If a device has the capability to initiate a many-to-one route request, it may also maintain a route record table (see Table 3.45).

3.6.3.3 Upon Receipt of a Unicast Frame

On receipt of a unicast frame from the MAC sub-layer, or an NLDE-DATA.request from the next higher layer, the NWK layer routes it according to the following procedure.

If the receiving device is a ZigBee router or ZigBee coordinator, and the destination of the frame is a ZigBee end device and also the child of the receiving device, the frame shall be routed directly to the destination using the MCPS-DATA.request primitive, as described in sub-clause 3.6.2.1. The frame shall also set the next hop destination address equal to the final destination address. Otherwise, for purposes of the ensuing discussion, define the *routing address* of a device to be its network address if it is a router or the coordinator or an end device and *nwkAddrAlloc* has a value of 0x02, or the network address of its parent if it is an end device and *nwkAddrAlloc* has a value of 0x00. Define the *routing destination* of a frame to be the routing address of the frame's NWK destination. Note that distributed address assignment makes it possible to derive the routing address of any device from its address. See sub-clause 3.6.1.6 for details.

A ZigBee router or ZigBee coordinator may check the neighbor table for an entry corresponding to the routing destination of the frame. If there is such an entry, the device may route the frame directly to the destination using the MCPS-DATA.request primitive as described in sub-clause 3.6.2.1.

A device that has routing capacity shall check its routing table for an entry corresponding to the routing destination of the frame. If there is such an entry, and if the value of the route status field for that entry is ACTIVE or VALIDATION_UNDERWAY, the device shall relay the frame using the MCPS-DATA.request primitive and set the route status field of that entry to ACTIVE if it does not already have that value. If the many-to-one field of the routing table entry is set to TRUE, the NWK shall follow the procedure outlined in sub-clause 3.6.3.5.4 to determine whether a route record command frame must be sent.

When relaying a unicast frame, the SrcAddrMode and DstAddrMode parameters of the MCPS-DATA.request primitive shall both have a value of 0x02, indicating 16-bit addressing. The SrcPANId and DstPANId parameters shall both have the value provided by the macPANId attribute of the MAC PIB for the relaying device. The SrcAddr parameter shall be set to the value of *macShortAddress* from the MAC PIB of the relaying device, and the DstAddr parameter shall be the value provided by the next-hop address field of the routing table entry corresponding to

the routing destination. Bit *b0* of the TxOptions parameter should be set to 1, indicating acknowledged transmission.

The NWK Sequence Number of a replayed packet shall not be changed by a router device relaying the packet. The router device relaying a packet shall leave the NWK Sequence Number of the originating device in the NWK Sequence Number field.

If the device has a routing table entry corresponding to the routing destination of the frame but the value of the route status field for that entry is DISCOVERY_UNDERWAY, the device shall determine if it initiated the discovery by consulting its discovery table. If the device initiated the discovery, the frame shall be treated as though route discovery has been initiated for this frame, otherwise, the device shall initiate route discovery as described in sub-clause 3.6.3.5.1. The frame may optionally be buffered pending route discovery or routed along the tree using hierarchical routing, provided that the NIB attribute *nwkUseTreeRouting* has a value of TRUE. If the frame is routed along the tree, the discover route sub-field of the NWK header frame control field shall be set to 0x00.

If the device has a routing table entry corresponding to the routing destination of the frame but the route status field for that entry has a value of DISCOVERY_FAILED or INACTIVE, the device may route the frame along the tree using hierarchical routing, provided that the NIB attribute *nwkUseTreeRouting* has a value of TRUE. If the device does not have a routing table entry for the routing destination with a status value of ACTIVE or VALIDATION_UNDERWAY, and it received the frame from the next higher layer, it shall check its source route table for an entry corresponding to the routing destination. If such an entry is found and the length is less than *nwkMaxSourceRoute*, the device shall transmit the frame using source routing as described in sub-clause 3.6.3.3.1. If the device does not have a routing table entry for the routing destination and it is not originating the frame using source routing, it shall examine the discover route sub-field of the NWK header frame control field. If the discover route sub-field has a value of 0x01, the device shall initiate route discovery, as described in sub-clause 3.6.3.5.1. If the discover route sub-field has a value of 0 and the NIB attribute *nwkUseTreeRouting* has a value of TRUE then the device shall route along the tree using hierarchical routing. If the discover route sub-field has a value of 0, the NIB attribute *nwkUseTreeRouting* has a value of FALSE, and there is no routing table corresponding to the routing destination of the frame, the frame shall be discarded and the NLDE shall issue the NLDE-DATA.confirm primitive with a status value of ROUTE_ERROR.

A device without routing capacity shall route along the tree using hierarchical routing provided that the value of the NIB attribute *nwkUseTreeRouting* is TRUE. If the value of the NIB attribute *nwkUseTreeRouting* is FALSE, the frame shall be discarded. If the frame is the result of an NLDE-DATA.request from the NHL of

the current device, the NLDE shall issue the NLDE-DATA.confirm primitive with a status value of ROUTE_ERROR. If the frame is being relayed on behalf of another device, the NLME shall issue a network status command frame destined for the device that is the source of the frame with a status of 0x04, indicating a lack of routing capacity. It shall also issue the NLME-NWK-STATUS.indication to the next higher layer with the NetworkAddr parameter equal to the 16-bit network address of the frame, and the Status parameter equal to 0x04, indicating a lack of routing capacity.

For hierarchical routing, if the destination is a descendant of the device, the device shall route the frame to the appropriate child. If the destination is a child, and it is also an end device, delivery of the frame can fail due to the *macRxOnWhenIdle* state of the child device. If the child has *macRxOnWhenIdle* set to FALSE, indirect transmission as described in IEEE 802.15.4-2003 [B1] may be used to deliver the frame. If the destination is not a descendant, the device shall route the frame to its parent.

Every other device in the network is a descendant of the ZigBee coordinator and no device in the network is the descendant of any ZigBee end device. For a ZigBee router with address A at depth d , if the following logical expression is true, then a destination device with address D is a descendant:

$$A < D < A + Cskip(d - 1)$$

For a definition of $Cskip(d)$, see sub-clause 3.6.1.6.

If it is determined that the destination is a descendant of the receiving device, the address N of the next hop device is given by:

$$N = D$$

for ZigBee end devices, where $D > A + Rm \times Cskip(d)$, and otherwise:

$$N = A + 1 + \left\lfloor \frac{D - (A + 1)}{Cskip(d)} \right\rfloor \times Cskip(d)$$

If the NWK layer on a ZigBee router or ZigBee coordinator fails to deliver a unicast or multicast frame for any reason, the router or coordinator shall make its best effort to report the failure. No failure should be reported as the result of a failure to deliver a NLME-NWK-STATUS. The failure reporting may take one of two forms. If the failed frame was being relayed as a result of a request from the next higher layer, then the NWK layer shall issue an NLDE-DATA.confirm with the error to the next higher layer. The value of the NetworkAddr parameter of the primitive shall be the intended destination of the frame. If the frame was being relayed on behalf of another device, then the relaying device shall send a network status command frame back to the source of the frame. The destination address

field of the network status command frame shall be taken from the destination address field of the failed data frame.

In either case, the reasons for failure that may be reported appear in Table 3.42.

3.6.3.3.1 Originating a Source Routed Data Frame

If, on receipt of a data frame from the next higher layer, it is determined that the frame should be transmitted using source routing as described above, the source route shall be retrieved from the route record table.

If there are no intermediate relay nodes, the frame shall be transmitted directly to the routing destination without source routing by using the MCPS-DATA.request primitive, with the DstAddr parameter value indicating the routing destination.

If there is at least one relay node, the source route flag of the NWK header frame control field shall be set, and the NWK header source route subframe shall be present. The relay count sub-field of the source route subframe shall have a value equal to the number of relays in the relay list. The relay index sub-field shall have a value equal to 1 less than the number of relays. The relay list sub-field shall contain the list of relay addresses, least significant octet first. The relay closest to the destination shall be listed first. The relay closest to the originator shall be listed last.

The device shall relay the frame using the MCPS-DATA.request primitive. The DstAddr parameter shall have the value of the final relay address in the relay list.

3.6.3.3.2 Relaying a Source Routed Data Frame

Upon receipt of a source routed data frame from the MAC sub-layer as described in sub-clause 3.6.3.3, if the relay index sub-field of the source route sub-frame has a value of 0, the device shall check the destination address field of the NWK header of the frame. If the destination address field of the NWK header of the frame is equal in value to the *nwkNetworkAddress* attribute of the NIB, then the frame shall be passed to the next higher layer using the NLDE-DATA.indication primitive. If the destination address field is not equal to the *nwkNetworkAddress* attribute of the NIB, and the receiving device is a ZigBee router or ZigBee coordinator, the device shall relay the frame directly to the NWK header destination using the MCPS-DATA.request primitive, otherwise the frame shall be discarded silently.

If the relay index sub-field has a value other than 0, the device shall compare its network address with the address found at the relay index in the relay list. If the addresses do not match, the frame shall be discarded and no further action shall be taken. Otherwise, as long as the destination address is not the address of an end device where the relaying device is the parent, the device shall decrement the relay index sub-field by 1, and relay the frame to the address immediately prior to its own address in the relay list sub-field. If the destination address of the frame is

an end device child of the relaying device, the frame shall be unicast using the MCPS-DATA.request primitive.

When relaying a source routed data frame, the NWK layer of a device shall also examine the routing table entry corresponding to the source address of the frame. If the no route cache field of the routing table entry has a value of FALSE, then the route record required field of the routing table entry shall be set to FALSE.

3.6.3.4 Link Status Messages

Wireless links may be asymmetric, that is, they may work well in one direction but not the other. This can cause route replies to fail, since they travel backwards along the links discovered by the route request.

For many-to-one routing and two-way route discovery (*nwkSymLink* = TRUE), it is a requirement to discover routes that are reliable in both directions. To accomplish this, routers exchange link cost measurements with their neighbors by periodically transmitting link status frames as a one-hop broadcast. The reverse link cost information is then used during route discovery to ensure that discovered routes use high-quality links in both directions.

3.6.3.4.1 Initiation of a Link Status Command Frame

When joined to a network, a ZigBee router or coordinator shall periodically send a link status command every *nwkLinkStatusPeriod* seconds, as a one-hop broadcast without retries. It may be sent more frequently if desired. Random jitter should be added to avoid synchronization with other nodes. See sub-clause 3.4.8 for the link status command frame format.

End devices do not send link status command frames.

3.6.3.4.2 Upon Receipt of a Link Status Command Frame

Upon receipt of a link status command frame by a ZigBee router or coordinator, the age field of the neighbor table entry corresponding to the transmitting device is reset to 0. The list of addresses covered by a frame is determined from the first and last addresses in the link status list, and the first frame and last frame bits of the command options field. If the receiver's network address is outside the range covered by the frame, the frame is discarded and processing is terminated. If the receiver's network address falls within the range covered by the frame, then the link status list is searched. If the receiver's address is found, the outgoing cost field of the neighbor table entry corresponding to the sender is set to the incoming cost value of the link status entry. If the receiver's address is not found, the outgoing cost field is set to 0.

End devices do not process link status command frames.

3.6.3.4.3 Aging the Neighbor Table

For devices using link status messages, the age fields for routers in the neighbor table are incremented every *nwkLinkStatusPeriod*. If the value exceeds *nwkRouterAgeLimit*, the outgoing cost field of the neighbor table entry is set to 0. In other words, if a device fails to receive *nwkRouterAgeLimit* link status messages from a router neighbor in a row, the old outgoing cost information is discarded. In this case, the neighbor entry is considered stale and may be reused if necessary to make room for a new neighbor. End devices do not issue link status messages and therefore should never be considered stale.

If *nwkAddrAlloc* has a value of 0x00, neighbor table entries for relatives should not be considered stale and reused.

3.6.3.5 Route Discovery

Route discovery is the procedure whereby network devices cooperate to find and establish routes through the NWK. *Unicast route discovery* is always performed with regard to a particular source device and a particular destination device. *Multicast route discovery* is performed with respect to a particular source device and a multicast group. *Many-to-one route discovery* is performed by a source device to establish routes to itself from all ZigBee routers and ZigBee coordinator, within a given radius. A source device that initiates a many-to-one route discovery is designated as a concentrator and referred to as such in this document. Throughout sub-clause 3.6.3.5 a *destination address* may be a 16-bit broadcast address, the 16-bit network address of a particular device, or a 16-bit multicast address, also known as a multicast group ID. A route request command whose destination address is the routing address of a particular device and whose route request option field does not have the multicast bit set, is a *unicast route request*. A route request command whose route request option field has the multicast bit set is a *multicast route request*. The destination address field of a multicast route request shall be a multicast group ID. A route request command payload whose destination address sub-field is a broadcast address (see Table 3.54) is a *many-to-one route request*. The multicast bit in the route request option field of a many-to-one route request shall be set to 0.

Note that on RREP new frames shall be created at every hop. In all other cases the packets shall not be not considered a “new” frame. A new frame shall be one with a new route request identifier. For RREP the sequence number is regenerated every hop. For RREC the sequence number does not change with every hop.

3.6.3.5.1 Initiation of Route Discovery

The unicast route discovery procedure for a device shall be initiated on a ZigBee router or ZigBee coordinator by the NWK layer up on receipt of an NLME-ROUTE-DISCOVERY.request primitive from the next higher layer where the DstAddrMode parameter has a value of 0x02. Or, up on receipt of an NLDE-

DATA.request primitive from a higher layer with the DstAddrMode set to 0x02 and the discover route sub-field set to 0x01, for which there is no routing table entry corresponding to the routing address of the destination device (the 16-bit network address indicated by the DstAddr parameter). Or, on receipt of a frame from the MAC sub-layer for which the value of the destination address field in the NWK header is not the address of the current device, the address of an end device child of the current device, or a broadcast address and:

- The discover route sub-field of the frame control field has a value of 0x01, and
- there is no routing table entry corresponding to the routing destination of the frame, and
- either the value of the source address field of the NWK header of the received frame is the same as the 16-bit network address of one of the end device children of the current device, or
- the *nwkUseTreeRouting* attribute of the NIB has a value of TRUE.

The route discovery procedure for a multicast address shall be initiated by the NWK layer either in response to the receipt of an NLME-ROUTE-DISCOVERY.request primitive from the next higher layer where the DstAddrMode parameter has a value of 0x01, or as specified in sub-clause 3.6.6.2.2.

If the device initiating route discovery has no routing table entry corresponding to the routing address of the destination device, it shall establish a routing table entry with status equal to DISCOVERY_UNDERWAY. If the device has an existing routing table entry corresponding to the routing address of the destination with status equal to ACTIVE or VALIDATION_UNDERWAY, that entry shall be used and the status field of that entry shall retain its current value. If it has an existing routing table entry with a status value other than ACTIVE or VALIDATION_UNDERWAY, that entry shall be used and the status of that entry shall be set to DISCOVERY_UNDERWAY. The device shall also establish the corresponding route discovery table entry if one with the same initiator and route request ID does not already exist.

Each device issuing a route request command frame shall maintain a counter used to generate route request identifiers. When a new route request command frame is created, the route request counter is incremented and the value is stored in the device's route discovery table in the Route request identifier field. Other fields in the routing table and route discovery table are set as described in sub-clause 3.6.3.2.

The NWK layer may choose to buffer the received frame pending route discovery or, if the frame is a unicast frame and the NIB attribute *nwkUseTreeRouting* has a value of TRUE, set the discover route sub-field of the frame control field in the NWK header to 0 and forward the data frame along the tree.

Once the device creates the route discovery table and routing table entries, the route request command frame shall be created with the payload depicted in Figure 3.12. The individual fields are populated as follows:

- The command frame identifier field shall be set to indicate the command frame is a route request, see Table 3.40.
- The Route request identifier field shall be set to the value stored in the route discovery table entry.
- The multicast flag and destination address fields shall be set in accordance with the destination address for which the route is to be discovered.
- The path cost field shall be set to 0.

Once created, the route request command frame is ready for broadcast and is passed to the MAC sub-layer using the MCPS-DATA.request primitive.

When broadcasting a route request command frame at the initiation of route discovery, the NWK layer shall retry the broadcast *nwkInitialRREQRetries* times after the initial broadcast, resulting in a maximum of *nwkInitialRREQRetries* + 1 transmissions. The retries will be separated by a time interval of *nwkRREQRetryInterval* OctetDurations.²⁷

The many-to-one route discovery procedure shall be initiated by the NWK layer of a ZigBee router or coordinator on receipt of an NLME-ROUTE-DISCOVERY.request primitive from the next higher layer where the DstAddrMode parameter has a value of 0x00. A many-to-one route request command frame is not retried; however, a discovery table entry is still created to provide loop detection during the *nwkRouteDiscoveryTime* period. If the NoRouteCache parameter of the NLME-ROUTE-DISCOVERY.request primitive is TRUE, the many-to-one sub-field of the command options field of the command frame payload shall be set to 2. Otherwise, the many-to-one sub-field shall be set to 1. Note that in this case, the NWK layer should maintain a route record table. The destination address field of the NWK header shall be set to 0xffff, the all-router broadcast address. The broadcast radius shall be set to the value in *nwkConcentratorRadius*. A source device that initiates a many-to-one route discovery is designated as a concentrator and referred to as such in this document and the NIB attribute *nwkIsConcentrator* should be set to TRUE. If a device has *nwkIsConcentrator* equal to TRUE and there is a non-zero value in *nwkConcentratorDiscoveryTime*, the network layer should issue a route request command frame each *nwkConcentratorDiscoveryTime*.

3.6.3.5.2 Upon Receipt of a Route Request Command Frame

Upon receipt of a route request command frame, if the device is an end device, it shall drop the frame. Otherwise, it shall determine if it has routing capacity.

27. ZigBee Document 12-0220-04

If the device does not have routing capacity and the route request is a multicast route request or a many-to-one-route request, the route request shall be discarded and route request processing shall be terminated.

If *nwkAddrAlloc* is 0x00 and the device does not have routing capacity and the route request is a unicast route request, the device shall check if the frame was received along a valid path. A path is valid if the frame was received from one of the device's children and the source device is a descendant of that child device, or if the frame was received from the device's parent device and the source device is not a descendant of the device. If the route request command frame was not received along a valid path, it shall be discarded. Otherwise, the device shall check if it is the intended destination. It shall also check if the destination of the command frame is one of its end device children by comparing the destination address field of the route request command frame payload with the address of each of its end device children, if any. If either the device or one of its end device children is the destination of the route request command frame, it shall reply with a route reply command frame. When replying to a route request with a route reply command frame, the device shall construct a frame with the frame type field set to 0x01. The route reply's source address shall be set to the 16-bit network address of the device creating the route reply and the destination address shall be set to the calculated next hop address, considering the originator of the route request as the destination. The link cost from the next hop device to the current device shall be computed as described in sub-clause 3.6.3.1 and inserted into the path cost field of the route reply command frame. The route reply command frame shall be unicast to the next hop device by issuing an MCPS-DATA.request primitive.

If the device is not the destination of the route request command frame, the device shall compute the link cost from the previous device that transmitted the frame, as described in sub-clause 3.6.3.1. This value shall be added to the path cost value stored in the route request command frame. The route request command frame shall then be unicast towards the destination using the MCPS-DATA.request service primitive. The next hop for this unicast transmission is determined in the same manner as if the frame were a data frame addressed to the device identified by the destination address field in the payload.

If the device does have routing capacity and the received request is a unicast route request, the device shall check if it is the destination of the command frame by comparing the destination address field of the route request command frame payload with its own address. It shall also check if the destination of the command frame is one of its end device children by comparing the destination address field of the route request command frame payload with the address of each of its end device children, if any. If neither the device nor one of its end device children is the destination of the route request command frame, the device shall determine if a route discovery table (see Table 3.53) entry exists with the same route request identifier and source address field. If no such entry exists, one shall be created.

If the device does have routing capacity and the multicast sub-field of the route request command options field of the received route request frame indicates a multicast route request, the device shall determine whether an entry already exists in the *nwkGroupIDTable* for which the group identifier field matches the destination address field of the frame. If a matching entry is found, the device shall determine if a route discovery table (see Table 3.53) entry exists with the same route request identifier and source address field. If no such entry exists, one shall be created.

For many-to-one route requests, and for regular route requests if the *nwkSymLink* attribute is TRUE, upon receipt of a route request command frame, the neighbor table is searched for an entry corresponding to the transmitting device. If no such entry is found, or if the outgoing cost field of the entry has a value of 0, the frame is discarded and route request processing is terminated. The maximum of the incoming and outgoing costs for the neighbor is used for the purposes of the path cost calculation, instead of the incoming cost. This includes the value used to increment the path cost field of the route request frame prior to retransmission.

When creating the route discovery table entry, the fields are set to the corresponding values in the route request command frame. The only exception is the forward cost field, which is determined by using the previous sender of the command frame to compute the link cost, as described in sub-clause 3.6.3.1, and adding it to the path cost contained the route request command frame. The result of the above calculation is stored in the forward cost field of the newly created route discovery table entry. If the *nwkSymLink* attribute is set to TRUE, the device shall also create a routing table entry with the destination address field set to the source address of the route request command frame and the next hop field set to the address of the previous device that transmitted the command frame. The status field shall be set to ACTIVE. The device shall then issue a route reply command frame to the source of the route request command frame. In the case that the device already has a route discovery table entry for the source address and route request identifier pair, the device shall determine if the path cost in the route request command frame is less than the forward cost stored in the route discovery table entry. The comparison is made by first computing the link cost from the previous device that sent this frame, as described in sub-clause 3.6.3.1, then adding it to the path cost value in the route request command frame. If this value is greater than the value in the route discovery table entry, the frame shall be dropped and no further processing is required. Otherwise, the forward cost and sender address fields in the route discovery table are updated with the new cost and the previous device address from the route request command frame.

If the *nwkSymLink* attribute is set to TRUE and the received route request command frame is a unicast route request, the device shall also create a routing table entry with the destination address field set to the source address of the route request command frame and the next hop field set to the address of the previous device that transmitted the command frame. The status field shall be set to

ACTIVE. The device shall then respond with a route reply command frame. In either of these cases, if the device is responding on behalf of one of its end device children, the responder address in the route reply command frame payload shall be set equal to the address of the end device child and not of the responding device.

When a device with routing capacity is not the destination of the received route request command frame, it shall determine if a route discovery table entry (see Table 3.53) exists with the same route request identifier and source address field. If no such entry exists, one shall be created. The route request timer shall be set to expire in *nwkRouteDiscoveryTime* OctetDurations.²⁸ If a routing table entry corresponding to the routing address of the destination exists and its status is not ACTIVE or VALIDATION_UNDERWAY, the status shall be set to DISCOVERY_UNDERWAY. If no such entry exists and the frame is a unicast route request, an entry shall be created and its status set to DISCOVERY_UNDERWAY. If the frame is a many-to-one route request, the device shall also create a routing table entry with the destination address field equal to the source address of the route request command frame by setting the next hop field to the address of the previous device that transmitted the command frame. If the frame is a many-to-one route request (*i.e.* the many-to-one sub-field of the command options field of the command frame payload has a non-zero value), the many-to-one field in the routing table entry shall be set to TRUE, and the no route cache flag shall be set to TRUE if the many-to-one sub-field of the command options field of the command frame payload has a value of 2 or to FALSE if it has a value of 1. If the routing table entry is new, or if the no route cache flag is set to TRUE, or if the next hop field changed, the route record required field shall be set to TRUE, otherwise it remains unchanged. The status field shall be set to ACTIVE. When the route request timer expires, the device deletes the route request entry from the route discovery table. When this happens, the routing table entry corresponding to the routing address of the destination shall also be deleted, if its status field has a value of DISCOVERY_UNDERWAY and there are no other entries in the route discovery table created as a result of a route discovery for that destination address.

If an entry in the route discovery table already exists, the path cost in the route request command frame shall be compared to the forward cost value in the route discovery table entry. The comparison is made by computing the link cost from the previous device, as described in sub-clause 3.6.3.1, and adding it to the path cost value in the route request command frame. If this path cost is greater, the route request command frame is dropped and no further processing is required. Otherwise, the forward cost and sender address fields in the route discovery table are updated with the new cost and the previous device address from the route request command frame. Additionally, the path cost field in the route request

28. ZigBee Document 12-0220-04

command frame shall be updated with the cost computed for comparison purposes. If the *nwkSymLink* attribute is set to TRUE and the received route request command frame is a unicast route request, the device shall also update any routing table entry with the destination address field set to the source address of the route request command frame, and the next hop field set to the address of the previous device that transmitted the command frame. The status field shall be set to ACTIVE. The device shall then broadcast the route request command frame using the MCPS-DATA.request primitive.

When broadcasting a route request command frame, the NWK layer shall delay retransmission by a random jitter amount calculated using the formula:

$$2 \times R[nwkcMinRREQJitter, nwkcMaxRREQJitter]$$

where $R[a, b]$ is a random function on the interval $[a, b]$. The units of this jitter amount are milliseconds. Implementers may adjust the jitter amount so that route request command frames arriving with large path cost are delayed more than frames arriving with lower path cost. The NWK layer shall retry the broadcast *nwkcRREQRetries* times after the original relay resulting in a maximum of *nwkcRREQRetries* + 1 relays per relay attempt. Implementers may choose to discard route request command frames awaiting retransmission in the case that a frame with the same source and route request identifier arrives with a lower path cost than the one awaiting retransmission.

The device shall also set the status field of the routing table entry corresponding to the routing address of the destination field in the payload to DISCOVERY_UNDERWAY. If no such entry exists, it shall be created.

When replying to a route request with a route reply command frame, a device that has a route discovery table entry corresponding to the source address and route request identifier of the route request shall construct a command frame with the frame type field set to 0x01. The source address field of the NWK header shall be set to the 16-bit network address of the current device and the destination address field shall be set to the value of the sender address field from the corresponding route discovery table entry. The device constructing the route reply shall populate the payload fields in the following manner.

- The NWK command identifier shall be set to route reply.
- The route request identifier field shall be set to the same value found in the route request identifier field of the route request command frame.
- The originator address field shall be set to the source address in the NWK header of the route request command frame.
- Using the sender address field from the route discovery table entry corresponding to the source address in the NWK header of the route request

command frame, the device shall compute the link cost as described in sub-clause 3.6.3.1. This link cost shall be entered in the path cost field.

The route reply command frame is then unicast to the destination by using the MCPS-DATA.request primitive and the sender address obtained from the route discovery table as the next hop.

3.6.3.5.3 Upon Receipt of a Route Reply Command Frame

On receipt of a route reply command frame, a device shall perform the following procedure.

If the receiving device has no routing capacity and its NIB attribute *nwkUseTreeRouting* has a value of TRUE, it shall send the route reply as though it were a data frame being forwarded using tree routing. If the receiving device has no routing capacity and its NIB attribute *nwkUseTreeRouting* has a value of FALSE, it shall discard the command frame. Before forwarding the route reply command frame the device shall update the path cost field in the payload by computing the link cost from the next hop device to itself as described in sub-clause 3.6.3.1 and adding this to the value in the route reply path cost field.

To support legacy devices, a route reply received with a radius of 1 shall NOT be dropped. It shall continue to be processed as follows.²⁹

If the receiving device has routing capacity, it shall check whether it is the destination of the route reply command frame by comparing the contents of the originator address field of the command frame payload with its own address. If it is, it shall search its route discovery table for an entry corresponding to the route request identifier in the route reply command frame payload. If there is no such entry, the route reply command frame shall be discarded and route reply processing shall be terminated. If a route discovery table entry exists, the device shall search its routing table for an entry with a destination address field equal to the routing address corresponding to the responder address in the route reply command frame. If there is no such routing table entry, the route reply command frame shall be discarded and, if a route discovery table entry corresponding to the route request identifier in the route reply command frame exists, it shall also be removed and route reply processing shall be terminated. If a routing table entry and a route discovery table entry exist and if the status field of the routing table entry is set to DISCOVERY_UNDERWAY, it shall be changed to VALIDATION_UNDERWAY if the routing table entry's GroupId flag is TRUE or to ACTIVE otherwise; the next hop field in the routing table shall be set to the previous device that forwarded the route reply command frame. The residual cost field in the route discovery table entry shall be set to the path cost field in the route reply payload.

29. CCB 1400/1414

If the status field was already set to ACTIVE or VALIDATION_UNDERWAY, the device shall compare the path cost in the route reply command frame to the residual cost recorded in the route discovery table entry, and update the residual cost field and next hop field in the routing table entry if the cost in the route reply command frame is smaller. If the path cost in the route reply is not smaller, the route reply shall be discarded and no further processing shall take place. Note that NLDE data requests may be processed as soon as the first valid route is determined.

If the device receiving the route reply is not the destination, the device shall find the route discovery table entry corresponding to the originator address and route request identifier in the route reply command frame payload. If no such route discovery table entry exists, the route reply command frame shall be discarded. If a route discovery table entry exists, the path cost value in the route reply command frame and the residual cost field in the route discovery table entry shall be compared. If the route discovery table entry value is less than the route reply value, the route reply command frame shall be discarded.

Otherwise, the device shall find the routing table entry with a destination address field equal to the routing address corresponding to the responder address in the route reply command frame. In this case, it is an error if the route discovery table entry exists and there is no corresponding routing table entry, and the route reply command frame should be discarded. The routing table entry shall be updated by replacing the next hop field with the address of the previous device that forwarded the route reply command frame. The route discovery table entry shall also be updated by replacing the residual cost field with the value in the route reply command frame.

Whenever the receipt of a route reply causes the next hop field of the corresponding routing table entry to be modified, and the routing table entry's GroupId flag is TRUE, the device shall set the expiration time field of the corresponding route discovery table entry to expire in *nwkcWaitBeforeValidation* OctetDurations if the device is the destination of the route reply and *nwkcRouteDiscoveryTime* OctetDurations if it is not.³⁰

After updating its own route entry, the device shall forward the route reply to the destination. Before forwarding the route reply, the path cost value shall be updated. The sender shall find the next hop to the route reply's destination by searching its route discovery table for the entry matching the route request identifier and the source address and extracting the sender address. It shall use this next hop address to compute the link cost as described in sub-clause 3.6.3.1. This cost shall be added to the path cost field in the route reply. The destination address in the command frame NWK header shall be set to the next hop address and the frame shall be unicast to the next hop device using the MCPS-DATA.request

30. ZigBee Document 12-0220-04

primitive. The `DstAddr` parameter of the `MCPS-DATA.request` primitive shall be set to the next-hop address from the route discovery table.

If the value of the `nwkSymLink` attribute of the NIB has a value of `TRUE`, the NWK layer shall, upon relaying the route reply command frame, also create a reverse routing table entry if such an entry does not yet exist. The value of the destination address field of the routing table entry shall correspond to the value of the originator address field of the route reply command frame. The status field shall have a value of `ACTIVE`. The next-hop address field shall have a value corresponding to the next hop address in the route reply command being relayed, as determined in the previous paragraph. If the reverse routing table entry already exists the next-hop address field shall be updated, if necessary.

3.6.3.5.4 Initiation and Processing of a Route Record Command Frame

If the NWK layer of a ZigBee router or ZigBee coordinator is initiating a unicast data frame as a result of an `NLDE-DATA.request` from the next higher layer and the many-to-one field of the routing table entry corresponding to the destination address of the frame has a value of `TRUE`, then the NWK layer shall examine the route record required field of that same routing table entry. If the route record required field also has a value of `TRUE`, the NWK shall unicast a route record command to the destination before transmitting the data frame.

If the NWK layer of a ZigBee router or ZigBee coordinator is forwarding a unicast data frame on behalf of one of its end device children and the many-to-one field of the destination's routing table entry has a value of `TRUE`, then the device shall unicast a route record command to the destination before relaying the data frame.

An optional optimization is possible in which the router or coordinator may keep track of which of its end device children have received source routed data frames from a particular concentrator device and can thereby reduce the number of route record commands it transmits to that concentrator on behalf of its end device children.

Each relay node that receives the route record command shall append its network address to the command payload, increment the relay count, and forward the message. If no next hop is available, or if delivery to the next hop fails, or if there is insufficient space in the payload for the network address, the command frame shall be discarded and no error command shall be generated.

Upon receipt of the route record command by the destination, the route shall be stored in the source route table. Any existing source routes to the message source or intermediary nodes shall be replaced by the new route information.

3.6.3.6 Upon Expiration of a Route Discovery Table Entry

When a route discovery table entry is created, the expiration timer shall be set to expire in *nwkcRouteDiscoveryTime* OctetDurations.³¹ For entries whose GroupId flag in the corresponding entry in the routing table is TRUE, when a route reply is received that causes the next hop to change, the expiration time field of the corresponding route discovery table entry is set to expire in *nwkcWaitBeforeValidation* OctetDurations if the device is the destination of the route reply and *nwkcRouteDiscoveryTime* OctetDurations if it is not.³² When the timer expires, the device shall delete the entry from the route discovery table. If the device is the originator of the route request and the routing table entry corresponding to the destination address has a Status field value of VALIDATION_UNDERWAY, then the device shall transmit a message to validate the route: either the message-buffered pending route discovery or a network status command with a status code of 0x0a (validate route). If the routing table entry corresponding to the destination address has any Status field value other than ACTIVE or VALIDATION_UNDERWAY and there are no other entries in the route discovery table corresponding to that routing table entry, the routing table entry shall also be deleted.

3.6.3.7 Route Maintenance

A device NWK layer shall maintain a failure counter for each neighbor to which it has an outgoing link, *i.e.*, to which it has been required to send data frames. If the outgoing link is classified as a failed link, then the device shall respond as described in the following paragraphs. Implementers may choose a simple failure-counting scheme to generate this failure counter value or they may use a more accurate time-windowed scheme. Note that it is important not to initiate repair too frequently since repair operations may flood the network and cause other traffic disruptions. The procedure for retiring links and ceasing to keep track of their failure counter is out of the scope of this specification.

3.6.3.7.1 In Case of Link Failure

If a failed link is encountered while a device is forwarding a unicast data frame using a routing table entry with the many-to-one field set to TRUE, a network status command frame with status code of 0x0c indicating many-to-one route failure shall be generated. The destination address field in the NWK header of the network status command frame shall be equal to the destination address field in the NWK header of the frame causing the error. The destination address field of the network status command payload shall be equal to the source address field in the NWK header of the frame causing the error. The network status command frame shall be unicast to a random router neighbor using the MCPS-

31. ZigBee Document 12-0220-04

32. ZigBee Document 12-0220-04

DATA.request primitive. Because it is a many-to-one route, all neighbors are expected to have a routing table entry to the destination. Upon receipt of the network status command frame, if no routing table entry for the destination is present, or if delivery of the network status command frame to the next hop in the routing table entry fails, the network status command frame shall again be unicast to a random router neighbor using the MCPS-DATA.request primitive. The radius counter in the NWK header will limit the maximum number of times the network status command frame is relayed. Upon receipt of the network status command frame by its destination it shall be passed up to the next higher layer using the NLME-NWK-STATUS.indication primitive. Many-to-one routes are not automatically rediscovered by the NWK layer due to route errors.

If a failed link is encountered while the device is forwarding a unicast frame using normal unicast routing, the device shall issue a network status command frame back to the source device of the frame with a status code indicating the reason for the failure (see Table 3.42), and issue an NLME-NWK-STATUS.indication to the next higher layer with a status code indicating the reason for the failure.

On receipt of a network status command frame by a router that is the intended destination of the command where the status code field of the command frame payload has a value of 0x01 or 0x02 indicating a link failure, the NWK layer will remove the routing table entry corresponding to the value of the destination address field of the command frame payload, if one exists, and inform the next higher layer of the failure using the NLME-NWK-STATUS.indication using the same status code.

On receipt of a network status command frame by a router that is the parent of an end device that is the intended destination, where the status code field of the command frame payload has a value of 0x01 or 0x02 indicating a link failure, the NWK layer will remove the routing table entry corresponding to the value of the destination address field of the command frame payload, if one exists. It will then relay the frame as usual to the end device.

On receipt of a network status command frame by an end device, the NWK layer shall inform the next higher layer of the failure using the NLME-NWK-STATUS.indication.

If an end device encounters a failed link to its parent, the end device shall inform the next higher layer using the NLME-NWK-STATUS.indication primitive with a Status parameter value of 0x09 indicating parent link failure (see Table 3.42). Similarly if a ZigBee router without routing capacity for which *nwkUseTreeRouting* has a value of TRUE encounters a failed link to its parent, it shall inform the next higher layer using the NLME-NWK-STATUS.indication primitive with a Status parameter value of 0x09 indicating parent link failure.

3.6.4 Scheduling Beacon Transmissions

Beacon scheduling is necessary in a multi-hop topology to prevent the beacon frames of one device from colliding with either the beacon frames or the data transmissions of its neighboring devices. Beacon scheduling is necessary when implementing a tree topology but not a mesh topology, as beaconing is not permitted in ZigBee mesh networks.

3.6.4.1 Scheduling Method

The ZigBee coordinator shall determine the beacon order and superframe order for every device in the network (see [B1] for more information on these attributes). Because one purpose of multi-hop beaconing networks is to allow routing nodes the opportunity to sleep in order to conserve power, the beacon order shall be set much larger than the superframe order. Setting the attributes in this manner makes it possible to schedule the active portion of the superframes of every device in any neighborhood such that they are non-overlapping in time. In other words, time is divided into approximately $(\text{macBeaconInterval} / \text{macSuperframeDuration})$ non-overlapping time slots, and the active portion of the superframe of every device in the network shall occupy one of these non-overlapping time slots. An example of the resulting frame structure for a single beaconing device is shown in Figure 3.46.

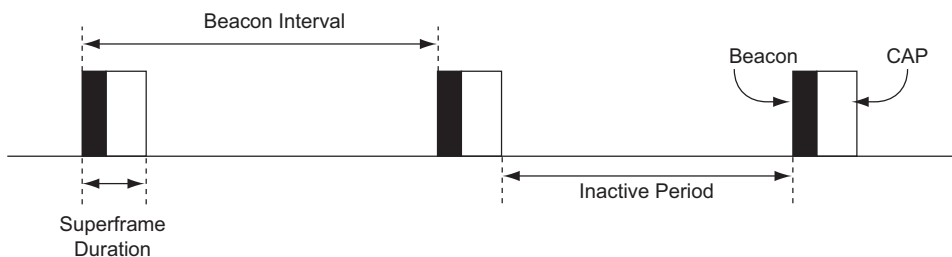


Figure 3.46 Typical Frame Structure for a Beaconing Device

The beacon frame of a device shall be transmitted at the start of its non-overlapping time slot, and the transmit time shall be measured relative to the beacon transmit time of the parent device. This time offset shall be included in the beacon payload of every device in a multi-hop beaconing network (see sub-clause 3.6.7 for a complete list of beacon payload parameters). Therefore a device receiving a beacon frame shall know the beacon transmission time of both the neighboring device and the parent of the neighboring device, since the transmission time of the parent may be calculated by subtracting the time offset from the timestamp of the beacon frame. The receiving device shall store both the local timestamp of the beacon frame and the offset included in the beacon payload in its neighbor table. The purpose of having a device know when the parent of its

neighbor is active is to maintain the integrity of the parent-child communication link by alleviating the hidden node problem. In other words, a device will never transmit at the same time as the parent of its neighbor.

Communication in a tree network shall be accomplished using the parent-child links to route along the tree. Since every child tracks the beacon of its parent, transmissions from a parent to its child shall be completed using the indirect transmission technique. Transmissions from a child to its parent shall be completed during the CAP of the parent. Details for the communication procedures can be found in IEEE 802.15.4-2003 [B1].

A new device wishing to join the network shall follow the procedure outlined in sub-clause 3.6.1.4. In the process of joining the network, the new device shall build its neighbor table based on the information collected during the MAC scan procedure. Using this information, the new device shall choose an appropriate time for its beacon transmission and CAP (the active portion of its superframe structure) such that the active portion of its superframe structure does not overlap with that of any neighbor or of the parent of any neighbor. If there is no available non-overlapping time slot in the neighborhood, the device shall not transmit beacons and shall operate on the network as an end device. If a non-overlapping time slot is available, the time offset between the beacon frames of the parent and the new device shall be chosen and included in the beacon payload of the new device. Any algorithm for selecting the beacon transmission time that avoids beacon transmission during the active portion of the superframes of its neighbors and their parents may be employed, as interoperability will be ensured.

To counteract drift, the new device shall track the beacon of its parent and adjust its own beacon transmission time such that the time offset between the two remains constant. Therefore, the beacon frames of every device in the network are essentially synchronized with those of the ZigBee coordinator. Figure 3.47 illustrates the relationship between the active superframe portions of a parent and its child.

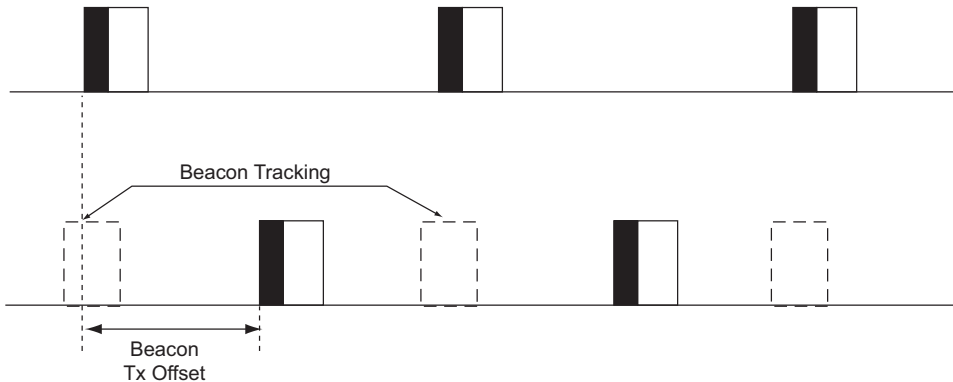


Figure 3.47 Parent-Child Superframe Positioning Relationship

The density of devices that can be supported in the network is inversely proportional to the ratio of the superframe order to the beacon order. The smaller the ratio, the longer the inactive period of each device and the more devices that can transmit beacon frames in the same neighborhood. It is recommended that a tree network utilize a superframe order of 0, which, when operating in the 2.4 GHz band, gives a superframe duration of 15.36 ms and a beacon order of between 6 and 10, which, in the 2.4 GHz band, gives a beacon interval between 0.98304s and 15.72864s. Using these superframe and beacon order values, a typical duty cycle for devices in the network will be between ~2% and ~0.1% regardless of the frequency band.

3.6.5 Broadcast Communication

This sub-clause specifies how a broadcast transmission is accomplished within a ZigBee network. Any device within a network may initiate a broadcast transmission intended for a number of other devices that are part of the same network. A broadcast transmission is initiated by the local APS sub-layer entity through the use of the NLDE-DATA.request primitive by setting the DstAddr parameter to a broadcast address as shown in Table 3.54, or by the NWK layer through the use of these same broadcast addresses in the construction of an outgoing NWK header. (Note that broadcast transmission for link status and route

request command frames is handled differently as described in sub-clause 3.6.3.4 and sub-clause 3.6.3.5.2 respectively.)

Table 3.54 Broadcast Addresses

Broadcast Address	Destination Group
0xffff	All devices in PAN
0xfffe	Reserved
0xfffd	<i>macRxOnWhenIdle</i> = TRUE
0xfffc	All routers and coordinator
0xfffb	Low power routers only
0xfff8 - 0xfffa	Reserved

To transmit a broadcast MSDU, the NWK layer of a ZigBee router or ZigBee coordinator issues an MCPS-DATA.request primitive to the MAC sub-layer with the DstAddrMode parameter set to 0x02 (16-bit network address) and the DstAddr parameter set to 0xffff. For a ZigBee end device, the MAC destination address of the broadcast frame shall be set equal to the 16-bit network address of the parent of the end device. The PANId parameter shall be set to the PANId of the ZigBee network. This specification does not support broadcasting across multiple networks. Broadcast transmissions shall not use the MAC sub-layer acknowledgement; instead, a passive acknowledgement mechanism may be used. Passive acknowledgement means that every ZigBee router and ZigBee coordinator keeps track of which of its neighboring devices have successfully relayed the broadcast transmission. The MAC sub-layer acknowledgement is disabled by setting the acknowledged transmission flag of the TxOptions parameter to FALSE. All other flags of the TxOptions parameter shall be set based on the network configuration.

The ZigBee coordinator, each ZigBee router and those ZigBee end devices with *macRxOnWhenIdle* equal to TRUE, shall keep a record of any new broadcast transaction that is either initiated locally or received from a neighboring device. This record is called the broadcast transaction record (BTR) and shall contain at least the sequence number and the source address of the broadcast frame. The

broadcast transaction records are stored in the *nwkBroadcastTransactionTable* (BTT) as shown in Table 3.55.

Table 3.55 Broadcast Transaction Record

Field Name	Size	Description
Source Address	2 bytes	The 16-bit network address of the broadcast initiator.
Sequence Number	1 byte	The NWK layer sequence number of the initiator's broadcast.
Expiration Time	1 byte	A countdown timer indicating the number of seconds until this entry expires; the initial value is <i>nwkNetworkBroadcastDeliveryTime</i> .

When a device receives a broadcast frame from a neighboring device, it shall compare the destination address of the frame with its device type. If the destination address does not correspond to the device type of the receiver as outlined in Table 3.54, the frame shall be discarded. If the destination address corresponds to the device type of the receiver, the device shall compare the sequence number and the source address of the broadcast frame with the records in its BTT.

If the device has a BTR of this particular broadcast frame in its BTT, it may update the BTR to mark the neighboring device as having relayed the broadcast frame. It shall then drop the frame. If no record is found, it shall create a new BTR in its BTT and may mark the neighboring device as having relayed the broadcast. The NWK layer shall then indicate to the higher layer that a new broadcast frame has been received using the NLDE-DATA.indication. If the device is a ZigBee router (ZR) or a ZigBee Coordinator (ZC) and the radius field is greater than zero; then the frame shall be retransmitted. Otherwise it shall be dropped. Before the retransmission, it shall wait for a random time period called broadcast jitter. This time period shall be bounded by the value of the *nwkMaxBroadcastJitter* attribute. ZigBee end devices with *macRxOnWhenIdle* equal to FALSE shall not participate in the relaying of broadcast frames and need not maintain a BTT for broadcast frames that they originate.

If, on receipt of a broadcast frame, the NWK layer finds that the BTT is full and contains no expired entries, then the frame should be dropped. In this situation the frame should not be retransmitted, nor should it be passed up to the next higher layer.

A ZigBee coordinator or ZigBee router operating in a non-beacon-enabled ZigBee network shall retransmit a previously broadcast frame at most *nwkMaxBroadcastRetries* times. If the device does not support passive acknowledgement, then it shall retransmit the frame exactly *nwkMaxBroadcastRetries* times. If the device supports passive acknowledgement and any of its neighboring devices have not relayed the broadcast frame within

nwkPassiveAckTimeout OctetDurations then it shall continue to retransmit the frame up to a maximum of *nwkMaxBroadcastRetries* times.³³

A device should change the status of a BTT entry after *nwkNetworkBroadcastDeliveryTime* OctetDurations³⁴ have elapsed since its creation. The entry status should change to expired and thus the entry can be overwritten if required when a new broadcast is received.

When a ZigBee router that has the *macRxOnWhenIdle* MAC PIB attribute set to FALSE receives a broadcast transmission, it shall use a different procedure for retransmission than the one outlined above. It shall retransmit the frame without delay to each of its neighbors individually, using a MAC layer unicast, that is, with the DstAddr parameter of the MCPS-DATA.request primitive set to the address of each neighbor device and not to the broadcast address. Similarly, a router or coordinator with the *macRxOnWhenIdle* MAC PIB attribute set to TRUE, which has one or more neighbors with the *macRxOnWhenIdle* MAC PIB attribute set to FALSE, shall, in the case where the destination address is 0xffff denoting broadcast to all devices, retransmit the broadcast frame to each of these neighbors in turn as a MAC layer unicast in addition to performing the more general broadcast procedure spelled out in the previous paragraphs. Indirect transmission, as described in IEEE 802.15.4-2003 [B1], may be employed to ensure that these unicasts reach their destination.

Every ZigBee router shall have the ability to buffer at least 1 frame at the NWK layer in order to facilitate retransmission of broadcasts.

Figure 3.48 shows a broadcast transaction between a device and two neighboring devices.

33. ZigBee Document 12-0220-04

34. ZigBee Document 12-0220-04

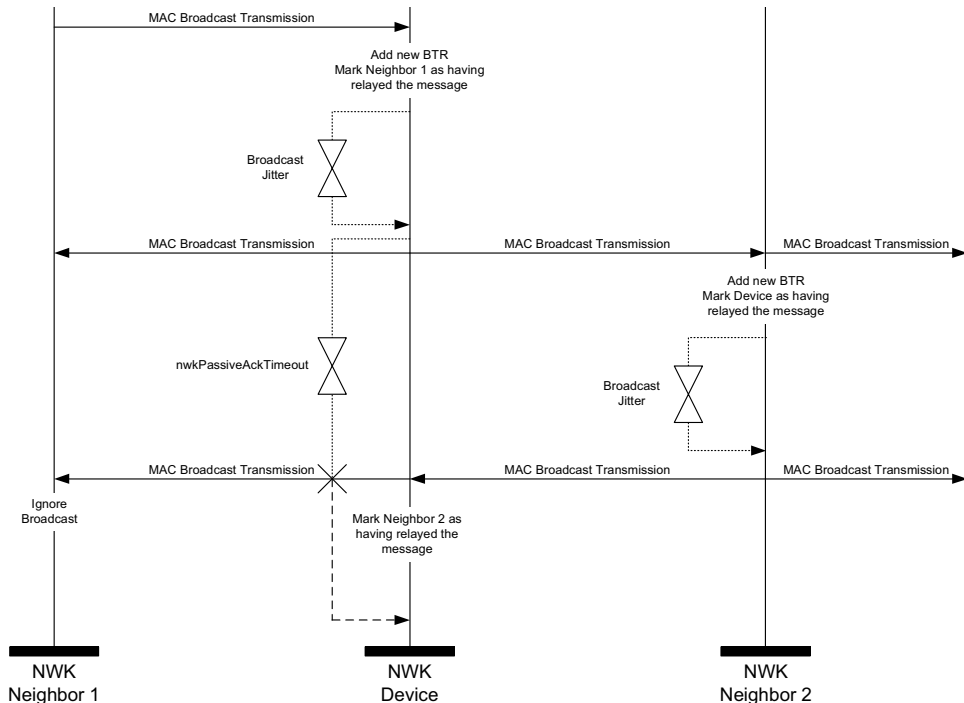


Figure 3.48 Broadcast Transaction Message Sequence Chart

3.6.6 Multicast Communication

This sub-clause specifies how multicast transmission is accomplished within a ZigBee network. Multicast addressing is accomplished using 16-bit multicast group IDs. A multicast group is a collection of nodes, all registered under the same multicast group ID, that are physically separated by a hop distance of no more than a given radius, known as the MaxNonMemberRadius. A multicast message is sent to a particular destination group and is received by all members of that group. Only data frames are multicast — no NWK command frames are multicast.

Multicast frames are propagated through the network by both members and non-members of the destination multicast group. A packet may be sent in one of two modes as indicated by a mode flag in the packet which determines the method of relay to the next hop. If the original message was created by a member of the group, it is considered to be in ‘Member Mode’ and is relayed by means of broadcasts. If the original message was created by a non-member of the group, it is considered to be in ‘Non-Member Mode’ and is relayed by means of unicasts towards a group member. Once a non-member message reaches any member of

the destination group, it is instantly transformed into a Member Mode type relay for the duration of the life of the packet regardless of who relays it next.

Multicast messages may be originated by end devices but are not sent to devices where *macRxOnWhenIdle* is equal to FALSE.

3.6.6.1 The Group ID Table

The NWK layer of a device may maintain a group ID table, *nwkGroupIDTable*, accessible as an attribute of the NIB as shown in Table 3.44. If the *nwkGroupIDTable* NIB attribute is present then it shall contain a set of 16-bit group identifiers for groups of which the device is a member.

Note that the optional *nwkGroupIDTable* NIB attribute has a functional overlap with the mandatory APS group table (see Table 2.18). If a device maintains both tables, and thereby expects to use NWK-layer multicast as a method for receiving group-addressed frames, it must assure that each 16-bit group identifiers that appears in the APS group table also appears in the NWK group table.

Note also that from an implementation perspective, it would be wasteful to duplicate the list of group identifiers across layers and it is assumed that implementers will find a way to combine the APS and NWK group tables to avoid waste.

3.6.6.2 Upon Receipt of a Multicast Frame from the Next Higher Layer

If an NLDE-DATA.request is received by the NWK layer from its next higher layer and the multicast control field is 0x01, the NWK layer shall determine whether an entry exists in the *nwkGroupIDTable* having a group identifier field matching the destination address of the frame. If a matching entry is found, the NWK layer shall multicast the frame according to the procedure outlined in sub-clause 3.6.6.2.1. If a matching entry is not found, the frame shall be initiated as a non-member mode multicast using the procedure outlined in sub-clause 3.6.6.2.2.

3.6.6.2.1 Initiating a Member Mode Multicast

The NWK layer shall set the multicast mode sub-field of the multicast control field to 0x01 (member mode). If the BTT table is full and contains no expired entries, the message shall not be sent and the NLDE shall issue the NLDE-DATA.confirm primitive with a status value of BT_TABLE_FULL. If the BTT is not full or contains an expired BTR, a new BTR shall be created with the local node as the source and the multicast frame's sequence number. The message shall then be transmitted according to the procedure described in the final paragraph of sub-clause 3.6.6.3.

3.6.6.2.2 Initiating a Non-Member Mode Multicast

The NWK layer shall set the multicast mode sub-field of the multicast control field to 0x00 (non-member mode). Then, the NWK layer shall check its routing table for an entry corresponding to the GroupID destination of the frame. If there is such an entry, the NWK layer shall examine the entry's status field. If the status is ACTIVE, then the device shall (re)transmit the frame. If the status is VALIDATION_UNDERWAY, then the status shall be changed to ACTIVE, the device shall transmit the frame according to the procedure described in the final paragraph of sub-clause 3.6.6.4, and the NLDE shall issue the NLDE-DATA.confirm primitive with the status value received from the MCPS-DATA.confirm primitive. If there is no routing table entry corresponding to the GroupID destination of the frame and the value of the DiscoverRoute parameter is 0x00 (suppress route discovery), the frame shall be discarded and the NLDE shall issue the NLDE-DATA.confirm primitive with a status value of ROUTE_DISCOVERY_FAILED. If the DiscoverRoute parameter has a value of 0x01 (enable route discovery) and there is no routing table entry corresponding to the GroupID destination of the frame, then the device shall initiate route discovery immediately as described in sub-clause 3.6.3.5.1. The frame may optionally be buffered pending route discovery. If it is not buffered, the frame shall be discarded and the NLDE shall issue the NLDE-DATA.confirm primitive with a status value of FRAME_NOT_BUFFERED.

3.6.6.3 Upon Receipt of a Member Mode Multicast Frame

When a device receives a member mode multicast frame from a neighboring device, it shall compare the sequence number and the source address of the multicast frame with the records in its BTT. If the device has a BTR of this particular multicast frame in its BTT it shall discard the frame. If no record is found and the BTT is full and contains no expired entries, it shall discard the frame. If no record is found and the BTT is not full or contains an expired BTR, it shall create a new BTR and continue processing the message as outlined in the following paragraph.

When a member mode multicast frame has been received from a neighbor and added to the BTT, the NWK layer shall then determine whether an entry exists in the *nwkGroupIDTable* whose group identifier field matches the destination group ID of the frame. If a matching entry is found, the message shall be passed to the next higher layer, the multicast mode sub-field of the multicast control field shall be set to 0x01 (member mode), the value of the NonmemberRadius sub-field shall be set to the value of the MaxNonmemberRadius sub-field in the multicast control field, and the message shall be transmitted as outlined in the following paragraph.

If a matching entry is not found, the NWK layer shall examine the frame's multicast NonmemberRadius field. If the value of the NonmemberRadius sub-field of the multicast field is 0 the message shall be discarded, along with the

newly added BTR. Otherwise, the NonmemberRadius sub-field shall be decremented if it is less than 0x07 and the frame shall be transmitted as outlined in following paragraphs. If, as a result of being decremented, this value falls to 0, the frame shall not, under any circumstances, be retransmitted.

Each member mode multicast message shall be transmitted *nwkMaxBroadcastRetries* times. For member mode multicast frames that did not originate on the local device, the initial transmission shall be delayed by a random time bounded by the value of the *nwkMaxBroadcastJitter* attribute. A device shall delay a period of *nwkPassiveAckTimeout* OctetDurations³⁵ between retransmissions of a particular member mode multicast message. Unlike broadcasts, there is no passive acknowledgement for multicasts. ZigBee end devices shall not participate in the relaying of multicast frames.

To transmit a member mode multicast MSDU, the NWK layer issues an MCPS-DATA.request primitive to the MAC sub-layer with the DstAddrMode parameter set to 0x02 (16-bit network address) and the DstAddr parameter set to 0xffff, which is the broadcast network address. The PANId parameter shall be set to the PANId of the ZigBee network. Member mode multicast transmissions shall not use the MAC sub-layer acknowledgement or the passive acknowledgement used for broadcasts. The MAC sub-layer acknowledgement is disabled by setting the acknowledged transmission flag of the TxOptions parameter to FALSE. All other flags of the TxOptions parameter shall be set based on the network configuration.

3.6.6.4 Upon Receipt of a Non-Member Mode Multicast Frame

When a device receives a non-member mode multicast frame from a neighboring device, the NWK layer shall determine whether an entry exists in the *nwkGroupIDTable* having a group identifier field that matches the destination address of the frame. If a matching entry is found, the multicast control field shall be set to 0x01 (member mode) and the message shall be processed as if it had been received as a member mode multicast. If no matching *nwkGroupIDTable* entry is found, the device shall check its routing table for an entry corresponding to the GroupID destination of the frame. If there is no such routing table entry, the message shall be discarded. If there is such an entry, the NWK layer shall examine the entry's status field. If the status is ACTIVE, the device shall (re)transmit the frame. If the status is VALIDATION_UNDERWAY, the status shall be changed to ACTIVE and the device shall (re)transmit the frame. To transmit a non-member mode multicast MSDU, the NWK layer issues an MCPS-DATA.request primitive to the MAC sublayer with the DstAddrMode parameter set to 0x02 (16-bit network address) and the DstAddr parameter set to the next hop as determined from the matching routing table entry. The PANId parameter shall be set to the

35. ZigBee Document 12-0220-04

PANId of the ZigBee network. The MAC sub-layer acknowledgement shall be enabled by setting the acknowledged transmission flag of the TxOptions parameter to TRUE. All other flags of the TxOptions parameter shall be set based on the network configuration.

3.6.7 NWK Information in the MAC Beacons

This sub-clause specifies how the NWK layer uses the beacon payload of a MAC sub-layer beacon frame to convey NWK layer-specific information to neighboring devices.

The beacon payload shall contain the information shown in Table 3.56. This enables the NWK layer to provide additional information to new devices that are performing network discovery and allows these new devices to more efficiently select a network and a particular neighbor to join. Refer to sub-clause 3.6.1.4.1.1 for a detailed description of the network discovery procedure.

Table 3.56 NWK Layer Information Fields

Name	Type	Valid Range	Description
Protocol ID	Integer	0x00 – 0xff	This field identifies the network layer protocols in use and, for purposes of this specification, shall always be set to 0, indicating the ZigBee protocols. The value 0xff shall also be reserved for future use by the ZigBee Alliance.
Stack profile	Integer	0x00 – 0x0f	A ZigBee stack profile identifier.
<i>nwkProtocolVersion</i>	Integer	0x00 – 0x0f	The version of the ZigBee protocol.
Router capacity	Boolean	TRUE or FALSE	This value is set to TRUE if this device is capable of accepting join requests from router-capable devices and is set to FALSE otherwise.
Device depth	Integer	0x00 – 0x0f	The network depth of this device. A value of 0x00 indicates that this device is the ZigBee coordinator for the network.
End device capacity	Boolean	TRUE or FALSE	This value is set to TRUE if the device is capable of accepting join requests from end devices seeking to join the network and is set to FALSE otherwise.

Table 3.56 NWK Layer Information Fields (Continued)

Name	Type	Valid Range	Description
<i>nwkExtendedPANId</i>	64-bit extended address	0x0000000000000001 – 0xfffffffffffffffe	The globally unique ID for the PAN of which the beaconing device is a member. By default, this is the 64-bit IEEE address of the ZigBee coordinator that formed the network, but other values are possible and there is no required structure to the address.
TxOffset	Integer	0x000000 – 0xffffff	This value indicates the difference in time, measured in symbols, between the beacon transmission time of the device and the beacon transmission time of its parent; This offset may be subtracted from the beacon transmission time of the device to calculate the beacon transmission time of the parent. This parameter is set to the default value of 0xFFFFF in beaconless networks.
<i>nwkUpdateId</i>	Integer	0x00 - 0xFF	This field reflects the value of <i>nwkUpdateId</i> from the NIB.

The NWK layer of the ZigBee coordinator shall update the beacon payload immediately following network formation. All other ZigBee devices shall update it immediately after the join is completed and any time the network configuration (any of the parameters specified in Table 3.10) changes. The beacon payload is written into the MAC sub-layer PIB using the MLME-SET.request primitive. The *macBeaconPayloadLength* attribute is set to the length of the beacon payload, and the octet sequence representing the beacon payload is written into the *macBeaconPayload* attribute. The formatting of the bit sequence representing the beacon payload is shown in Figure 3.48.

Bits: 0–7	8–11	12–15	16–17	18	19–22	23	24–87	88–111	112–119
Protocol ID	Stack profile	<i>nwkProtocolVersion</i>	Reserved	Router capacity	Device depth	End device capacity	<i>nwkExtendedPANId</i>	Tx Offset	<i>nwkUpdateId</i>

Figure 3.49 Format of the MAC Sub-Layer Beacon Payload

3.6.8 Persistent Data

Devices operating in the field may be reset either manually or programmatically by maintenance personnel, or may be reset accidentally for any number of reasons, including localized or network-wide power failures, battery replacement during the course of normal maintenance, impact, and so on. The following information should be preserved across resets in order to maintain an operating network:

- The device's PAN Id and Extended PAN Id.
- The device's 16-bit network address.
- The 64-bit IEEE address and 16-bit network address of each associated end device child and if *nwkAddrAlloc* is equal to 0 then also each associated router child.
- For end devices, the 16-bit network address of the parent device.
- The stack profile in use.
- The device depth.

The method by which these data are made to persist is beyond the scope of this specification.

3.6.9 Low Power Routers (LPR)

Low power routers are defined as routers operating on batteries for multiple years by regularly powering off their radios. LPRs shall be recognized by high power routers (HPR) looking at the following capability information bit-fields (see Table 3.47) during the joining phase:

- Device type set to 1
- Receive on when idle set to FALSE

LPR devices should be able to receive network command frames that are broadcast in the network. This can be achieved by setting the destination address in the NWK header to the broadcast address for all routers and coordinators (see Table 3.54).

3.7 NWK Layer Status Values

Network (NWK) layer confirmation primitives often include a parameter that reports on the status of the request to which the confirmation applies. Values for NWK layer Status parameters appear in Table 3.57.

Table 3.57 NWK Layer Status Values

Name	Value	Description
SUCCESS	0x00	A request has been executed successfully.
INVALID_PARAMETER	0xc1	An invalid or out-of-range parameter has been passed to a primitive from the next higher layer.
INVALID_REQUEST	0xc2	The next higher layer has issued a request that is invalid or cannot be executed given the current state of the NWK layer.
NOT_PERMITTED	0xc3	An NLME-JOIN.request has been disallowed.
STARTUP_FAILURE	0xc4	An NLME-NETWORK-FORMATION.request has failed to start a network.
ALREADY_PRESENT	0xc5	A device with the address supplied to the NLME-DIRECT-JOIN.request is already present in the neighbor table of the device on which the NLME-DIRECT-JOIN.request was issued.
SYNC_FAILURE	0xc6	Used to indicate that an NLME-SYNC.request has failed at the MAC layer.
NEIGHBOR_TABLE_FULL	0xc7	An NLME-JOIN-DIRECTLY.request has failed because there is no more room in the neighbor table.
UNKNOWN_DEVICE	0xc8	An NLME-LEAVE.request has failed because the device addressed in the parameter list is not in the neighbor table of the issuing device.
UNSUPPORTED_ATTRIBUTE	0xc9	An NLME-GET.request or NLME-SET.request has been issued with an unknown attribute identifier.
NO_NETWORKS	0xca	An NLME-JOIN.request has been issued in an environment where no networks are detectable.
Reserved	0xcb	
MAX_FRM_COUNTER	0xcc	Security processing has been attempted on an outgoing frame, and has failed because the frame counter has reached its maximum value.
NO_KEY	0xcd	Security processing has been attempted on an outgoing frame, and has failed because no key was available with which to process it.
BAD_CCM_OUTPUT	0xce	Security processing has been attempted on an outgoing frame, and has failed because the security engine produced erroneous output.
Reserved	0xcf	
ROUTE_DISCOVERY_FAILED	0xd0	An attempt to discover a route has failed due to a reason other than a lack of routing capacity.

Table 3.57 NWK Layer Status Values (Continued)

Name	Value	Description
ROUTE_ERROR	0xd1	An NLDE-DATA.request has failed due to a routing failure on the sending device or an NLME-ROUTE-DISCOVERY.request has failed due to the cause cited in the accompanying NetworkStatusCode.
BT_TABLE_FULL	0xd2	An attempt to send a broadcast frame or member mode multicast has failed due to the fact that there is no room in the BTT.
FRAME_NOT_BUFFERED	0xd3	An NLDE-DATA.request has failed due to insufficient buffering available. A non-member mode multicast frame was discarded pending route discovery.

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CHAPTER

4

SECURITY SERVICES SPECIFICATION

4.1 Document Organization

The remaining portions of this document specify in greater detail the various security services available within the ZigBee stack. Basic definitions and references are given in clause 4.2. A general description of the security services is given in sub-clause 4.2.1. In this clause, the overall security architecture is discussed; basic security services provided by each layer of this architecture are introduced. Sub-clauses 4.2.2 and 4.2.3 give the ZigBee Alliance's security specifications for the Network (NWK) layer and the Application Support Sublayer (APS) layer, respectively. These clauses introduce the security mechanisms, give the primitives, and define any frame formats used for security purposes. Clause 4.5 describes security elements common to the NWK and APS layers. Clause 4.6 provides a basic functional description of the available security features. Finally, annexes provide technical details and test vectors needed to implement and test the cryptographic mechanisms and protocols used by the NWK and APS layers.

4.2 General Description

Security services provided for ZigBee include methods for key establishment, key transport, frame protection, and device management. These services form the building blocks for implementing security policies within a ZigBee device. Specifications for the security services and a functional description of how these services shall be used are given in this document.

4.2.1 Security Architecture and Design

In this clause, the security architecture is described. Where applicable, this architecture complements the security services that are already present in the IEEE Std. 802.15.4 802 [B1] security specification.

4.2.1.1 Security Assumptions

The level of security provided by the ZigBee security architecture depends on the safekeeping of the symmetric keys, on the protection mechanisms employed, and on the proper implementation of the cryptographic mechanisms and associated security policies involved. Trust in the security architecture ultimately reduces to trust in the secure initialization and installation of keying material and to trust in the secure processing and storage of keying material.

Implementations of security protocols, such as key establishment, are assumed to properly execute the complete protocol and not to leave out any steps thereof. Random number generators are assumed to operate as expected. Furthermore, it is assumed that secret keys do not become available outside the device in an unsecured way. That is, a device will not intentionally or inadvertently transmit its keying material to other devices unless the keying material is protected, such as during key-transport. An exception to this assumption occurs when a device that has not been preconfigured joins the network. In this case, a single key may be sent unprotected, thus resulting in a brief moment of vulnerability where the key could be obtained by any device. This can lead to a critical security compromise if it is possible for an untrusted device to obtain the key.

The following caveat in these assumptions applies: due to the low-cost nature of *ad hoc* network devices, one cannot generally assume the availability of tamper-resistant hardware. Hence, physical access to a device may yield access to secret keying material and other privileged information, as well as access to the security software and hardware.

Due to cost constraints, ZigBee has to assume that different applications using the same radio are not logically separated (for example, by using a firewall). In addition, from the perspective of a given device it is not even possible (barring certification) to verify whether cryptographic separation between different applications on another device — or even between different layers of the communication stack thereof — is indeed properly implemented. Hence, one must assume that separate applications using the same radio trust each other; that is, there is no cryptographic task separation. Additionally, lower layers (for example, APS, NWK, or MAC) are fully accessible by any of the applications. These assumptions lead to an open trust model for a device; different layers of the communication stack and all applications running on a single device trust each other.

In summary:

- The provided security services cryptographically protect the interfaces between different devices only.
- Separation of the interfaces between different stack layers on the same device is arranged non-cryptographically, via proper design of security service access points.

4.2.1.2 Security Design Choices

The open trust model (as described in sub-clause 4.2.1.1) on a device has far-reaching consequences. It allows re-use of the same keying material among different layers on the same device and it allows end-to-end security to be realized on a device-to-device basis rather than between pairs of particular layers (or even pairs of applications) on two communicating devices.

However, one must also take into consideration whether one is concerned with the ability of malevolent network devices to use the network to transport frames across the network without permission.

These observations lead to the following architectural design choices:

- First, the principle that “*the layer that originates a frame is responsible for initially securing it*” is established. For example, if a NWK command frame needs protection, NWK layer security shall be used.
- Second, if protection from theft of service is required (*i.e.*, from malevolent network devices), NWK layer security shall be used for all frames, except those passed between a router and a newly joined device (until the newly joined device receives the active network key). Thus, only a device that has joined the network and successfully received the active network key will be able to have its messages communicated more than one hop across the network.
- Third, due to the open trust model, security can be based on the reuse of keys by each layer. For example, the active network key shall be used to secure APS layer broadcast frames or NWK layer frames. Reuse of keys helps reduce storage costs.
- Fourth, end-to-end security is enabled such that it is possible for only source and destination devices to access their shared key. This limits the trust requirement to those devices whose information is at stake. Additionally, it ensures that routing of messages between devices can be realized independent of trust considerations (thus if security is used, facilitating considerable separation of concern).
- Fifth, to simplify interoperability of devices, the security level used by all devices in a given network, and by all layers of a device, shall be the same. If

an application needs more security for its payload than is provided by a given network, it shall form its own separate network with a higher security level.

There are several policy decisions which any real implementation must address correctly. Application profiles should include policies to:

- Handle error conditions arising from securing and unsecuring packets. Some error conditions may indicate loss of synchronization of security material, or may indicate ongoing attacks.
- Detect and handle loss of counter synchronization and counter overflow.
- Detect and handle loss of key synchronization.
- Expire and periodically update keys, if desired.

4.2.1.3 Security Keys

Security amongst a network of ZigBee devices is based on “link” keys and a “network” key. Unicast communication between APL peer entities is secured by means of a 128-bit link key shared by two devices, while broadcast communications are secured by means of a 128-bit network key shared amongst all devices in the network. The intended recipient is always aware of the exact security arrangement; that is, the recipient knows whether a frame is protected with a link key or a network key.

A device shall acquire link keys either via key-transport, key-establishment, or pre-installation (for example, during factory installation). A device shall acquire a network key via key-transport or pre-installation. The key-establishment technique for acquiring a link key (see sub-clause 4.2.3.1) is based on a “master” key. A device shall acquire a master key (for purposes of establishing corresponding link keys) via key-transport or pre-installation. Ultimately, security between devices depends on secure initialization and installation of these keys.

There are two different types of network keys: standard, and high-security. The type controls how a network key is distributed; and may control how network frame counters are initialized. The type does not affect how messages are secured.

There are two different types of link keys: global and unique. The type of link key in use by the local device shall determine how the device handles various trust center messages (APS commands), including whether to apply APS encryption.

A default global trust center link key must be supported by the device if no other link key is specified by the application at the time of joining. This default link key shall have a value of 5A 69 67 42 65 65 41 6C 6C 69 61 6E 63 65 30 39 (ZigBeeAlliance09).³⁶

36. CCB 1039

In a secured network there are a variety of security services available. Prudence dictates that one would prefer to avoid re-use of keys across different security services, which otherwise could cause security leaks due to unwanted interactions. As such, these different services use a key derived from a one-way function using the link key (as specified in sub-clause 4.5.3). The use of uncorrelated keys ensures logical separation of the execution of different security protocols. The key-load key is used to protect transported master and link keys; the key-transport key is used to protect transported network keys. The active network key may be used by the NWK and APL layers of ZigBee. As such, the same network key and associated outgoing and incoming frame counters shall be available to all of these layers. The link and master keys may be used only by the APS sublayer. As such, the link and master keys shall be available only to the APL layer.

4.2.1.4 ZigBee Security Architecture

The ZigBee security architecture includes security mechanisms at two layers of the protocol stack. The NWK and APS layers are responsible for the secure transport of their respective frames. Furthermore, the APS sublayer provides services for the establishment and maintenance of security relationships. The ZigBee Device Object (ZDO) manages the security policies and the security configuration of a device. Figure 1.1 shows a complete view of the ZigBee protocol stack. The security mechanisms provided by the APS and NWK layers are described in this version of the specification.

4.2.2 NWK Layer Security

When a frame originating at the NWK layer needs to be secured, or when a frame originates at a higher layer and the *nwkSecureAllFrames* attribute in the NIB is TRUE, ZigBee shall use the frame-protection mechanism given in sub-clause 4.3.1 of this specification, unless the *SecurityEnable* parameter of the NLDE-DATA.request primitive is FALSE, explicitly prohibiting security. The NWK layer's frame-protection mechanism shall make use of the Advanced Encryption Standard (AES) [B8] and use CCM* as specified in Annex A. The security level applied to a NWK frame shall be determined by the *nwkSecurityLevel* attribute in the NIB. Upper layers manage NWK layer security by setting up active and alternate network keys and by determining which security level to use.

Figure 4.1 shows an example of the security fields that may be included in a NWK frame.

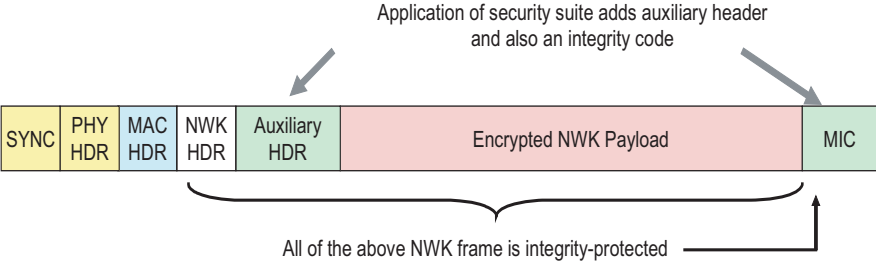


Figure 4.1 ZigBee Frame with Security on the NWK Level

4.2.3 APL Layer Security

When a frame originating at the APL layer needs to be secured, the APS sublayer shall handle security. The APS layer's frame-protection mechanism is given in sub-clause 4.4.1 of this specification. The APS layer allows frame security to be based on link keys or the network key. Figure 4.2 shows an example of the security fields that may be included in an APL frame. The APS layer is also responsible for providing applications and the ZDO with key establishment, key transport, and device management services.

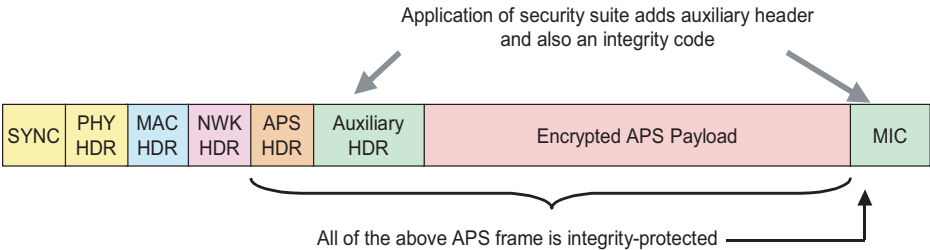


Figure 4.2 ZigBee Frame with Security on the APS Level

4.2.3.1 Key Establishment

The APS sublayer's key-establishment services provide the mechanism by which a ZigBee device may derive a shared secret key (the so-called "link key", see sub-clause 4.2.1.3), with another ZigBee device. Key establishment involves two entities, an initiator device and a responder device, and is prefaced by a trust-provisioning step.

Trust information (for example, a master key) provides a starting point for establishing a link key and can be provisioned in-band or out-of-band. Once trust information is provisioned, a key-establishment protocol involves three conceptual steps:

- The exchange of ephemeral data.
- The use of this ephemeral data to derive the link key.
- The confirmation that this link key was correctly computed.

In the Symmetric-Key Key Establishment (SKKE) protocol, an initiator device establishes a link key with a responder device using a master key. This master key, may be pre-installed during manufacturing, may be installed by a Trust Center (for example, from the initiator, the responder, or a third party device acting as a Trust Center), or may be based on user-entered data (for example: PIN, password, or key). The secrecy and authenticity of the master key needs to be upheld in order to maintain a trust foundation.

4.2.3.2 Transport Key

The transport-key service provides secured and unsecured means to transport a key to another device or other devices. The secured transport-key command provides a means to transport a master, link, or network key from a key source (for example, the Trust Center) to other devices. The unsecured transport-key command provides a means for loading a device with an initial key. This command does not cryptographically protect the key being loaded. In this case, the security of the transported key can be realized by non-cryptographic means; for example, by communicating the command via an out-of-band channel that guarantees secrecy and authenticity.

4.2.3.3 Update Device

The update device service provides a secure means for a device (e.g., a router) to inform a second device (for example, a Trust Center) that a third device has had a change of status that must be updated (for example, the device joined or left the network). This is the mechanism by which the Trust Center maintains an accurate list of active network devices.

4.2.3.4 Remove Device

The remove device service provides a secure means by which a device (for example, a Trust Center) may inform another device (for example, a router) that one of its children should be removed from the network. For example, the remove device service may be employed to remove from a network a device that has not satisfied the Trust Center's security requirements for network devices.

4.2.3.5 Request Key

The request-key service provides a secure means for a device to request the active network key, or an end-to-end application master key, from another device (for example, its Trust Center).

4.2.3.6 Switch Key

The switch-key service provides a secure means for a device (for example, a Trust Center) to inform another device that it should switch to a different active network key.

4.2.3.7 Entity Authentication

The entity authentication service provides a secure means for a device to synchronize information with another device while simultaneously providing authenticity based on a shared key.

4.2.3.8 Permissions Configuration Table

The permissions configuration table indicates which devices have authorization to carry out certain types of commands, and determines in each case whether or not link key security is required.

4.2.4 Trust Center Role

For security purposes, ZigBee defines the role of “Trust Center”. The Trust Center is the device trusted by devices within a network to distribute keys for the purpose of network and end-to-end application configuration management. All members of the network shall recognize exactly one Trust Center, and there shall be exactly one Trust Center in each secure network.

In high-security, commercial applications (see sub-clause 4.6.2.1) a device can be pre-loaded with the Trust Center address and initial master key. Alternatively, if the application can tolerate a moment of vulnerability, the master key can be sent via an in-band unsecured key transport. If not pre-loaded, a device's Trust Center defaults to the ZigBee coordinator or a device designated by the ZigBee coordinator.

In low-security, residential applications (see sub-clause 4.6.2.2) a device securely communicates with its Trust Center using the current network key, which can be preconfigured or sent via an in-band unsecured key transport.

For purposes of trust management, a device accepts an initial master or active network key originating from its Trust Center via unsecured key transport. For purposes of network management, a device accepts an initial active network key and updated network keys only from its Trust Center. For purposes of configuration, a device accepts master keys or link keys intended for establishing end-to-end security between two devices only from its Trust Center. Aside from the initial master key or network key, additional link, master, and network keys are generally only accepted if they originate from a device's Trust Center via secured key transport.

4.3 NWK Layer Security

The NWK layer is responsible for the processing steps needed to securely transmit outgoing frames and securely receive incoming frames. Upper layers control the security processing operations by setting up the appropriate keys and frame counters and establishing which security level to use.

4.3.1 Frame Security

The detailed steps involved in security processing of outgoing and incoming NWK frames are described in sub-clauses 4.3.1.1 and 4.3.1.2, respectively.

4.3.1.1 Security Processing of Outgoing Frames

If the NWK layer has a frame, consisting of a header *NwkHeader* and payload *Payload*, which needs security protection and *nwkSecurityLevel* > 0, and in the case of a NWK data frame, the *SecurityEnabled* parameter in NLDE-DATA.request had a value of TRUE, it shall apply security as follows:

- 1 Obtain the *nwkActiveKeySeqNumber* from the NIB and use it to retrieve the active network key *key*, outgoing frame counter *OutgoingFrameCounter*, and key sequence number *KeySeqNumber* from the *nwkSecurityMaterialSet* attribute in the NIB. Obtain the security level from the *nwkSecurityLevel* attribute from the NIB. If the outgoing frame counter has as its value the 4-octet representation of the integer $2^{32}-1$, or if the key cannot be obtained, security processing shall fail and no further security processing shall be done on this frame.
- 2 Construct the auxiliary header *AuxiliaryHeader* (see sub-clause 4.5.1):
 - a Set the security control field as follows:
 - i The security level sub-field shall be the security level obtained from step 1.
 - ii The key identifier sub-field shall be set to '01' (that is, the active network key).
 - iii The extended nonce sub-field shall be set to 1.
 - b Set the source address field to the 64-bit extended address of the local device.
 - c Set the frame counter field to the outgoing frame counter from step 1.
 - d Set the key sequence number field to the sequence number from step 1.
- 3 Execute the CCM* mode encryption and authentication operation, as specified in Annex A, with the following instantiations:

- a Obtain the parameter *M* from Table 4.40 corresponding to the security level from step 1;
 - b The bit string *Key* shall be the key obtained from step 1;
 - c The nonce *N* shall be the 13-octet string constructed using the security control field from step a, the frame counter field from step d, and the source address field from step c (see sub-clause 4.5.2.2);
 - d If the security level requires encryption, the octet string *a* shall be the string *NwkHeader* || *AuxiliaryHeader* and the octet string *m* shall be the string *Payload*. Otherwise, the octet string *a* shall be the string *NwkHeader* || *AuxiliaryHeader* || *Payload* and the octet string *m* shall be a string of length zero.
- 4 If the CCM* mode invoked in step 3 outputs 'invalid', security processing shall fail and no further security processing shall be done on this frame.
 - 5 Let *c* be the output from step 3. If the security level requires encryption, the secured outgoing frame shall be *NwkHeader* || *AuxiliaryHeader* || *c*, otherwise the secured outgoing frame shall be *NwkHeader* || *AuxiliaryHeader* || *Payload* || *c*.
 - 6 If the secured outgoing frame size is greater than *aMaxMACFrameSize* (see IEEE Std. 802.15.4 802 [B1]), security processing shall fail and no further security processing shall be done on this frame.
 - 7 The outgoing frame counter from step 1 shall be incremented by one and stored in the *OutgoingFrameCounter* element of the network security material descriptor referenced by the *nwkActiveKeySeqNumber* in the NIB; that is, the outgoing frame counter value associated with the key used to protect the frame is updated.
 - 8 The security level sub-field of the security control field shall be over-written by the 3-bit all-zero string '000'.

4.3.1.2 Security Processing of Incoming Frames

If the NWK layer receives a secured frame (consisting of a header *NwkHeader*, auxiliary header *AuxiliaryHeader*, and payload *SecuredPayload*) as indicated by the security sub-field of the NWK header frame control field, it shall perform security processing as follows:

- 1 Determine the security level from the *nwkSecurityLevel* attribute of the NIB. Over-write the 3-bit security level sub-field of the security control field of the *AuxiliaryHeader* with this value. Determine the sequence number *SequenceNumber*, sender address *SenderAddress*, and received frame count *ReceivedFrameCount* from the auxiliary header *AuxiliaryHeader* (see sub-clause 4.5.1). If *ReceivedFrameCounter* has as value the 4-octet representation

- of the integer $2^{32}-1$, security processing shall indicate a failure to the next higher layer with a status of 'bad frame counter' and no further security processing shall be done on this frame.
- 2 Obtain the appropriate security material (consisting of the key and other attributes) by matching *SequenceNumber* to the sequence number of any key in the *nwkSecurityMaterialSet* attribute in the NIB. If the neighbor table entry corresponding to *SenderAddress* has a relationship field with value 0x01 (child), that field shall be set to the value 0x05 (unauthenticated child). If the security material cannot be obtained, security processing shall indicate a failure to the next higher layer with a status of 'frame security failed' and no further security processing shall be done on this frame.
 - 3 If there is an incoming frame count *FrameCount* corresponding to *SenderAddress* from the security material obtained in step 2 and if *ReceivedFrameCount* is less than *FrameCount*, security processing shall indicate a failure to the next higher layer with a status of 'bad frame counter' and no further security processing shall be done on this frame.
 - 4 Execute the CCM* mode decryption and authentication checking operation, as specified in sub-clause A.2, with the following instantiations:
 - a The parameter *M* shall be obtained from Table 4.40 corresponding to the security level from step 1.
 - b The bit string *Key* shall be the key obtained from step 2.
 - c The nonce *N* shall be the 13-octet string constructed using the security control, the frame counter, and the source address fields from *AuxiliaryHeader* (see sub-clause 4.5.2.2). Note that the security level sub-field of the security control field has been overwritten in step 1 and now contains the value determined from the *nwkSecurityLevel* attribute from the NIB.
 - d The octet string *SecuredPayload* shall be parsed as *Payload₁* || *Payload₂*, where the rightmost string *Payload₂* is an *M*-octet string. If this operation fails, security processing shall indicate a failure to the next higher layer with a status of 'frame security failed' and no further security processing shall be done on this frame.
 - e If the security level requires decryption, the octet string *a* shall be the string *NwkHeader* || *AuxiliaryHeader* and the octet string *c* shall be the string *SecuredPayload*. Otherwise, the octet string *a* shall be the string *NwkHeader* || *AuxiliaryHeader* || *Payload₁* and the octet string *c* shall be the string *Payload₂*.
 - 5 Return the results of the CCM* operation:

- a

If the CCM* mode invoked in step 4 outputs ‘invalid’, security processing shall indicate a failure to the next higher layer with a status of ‘frame security failed’ and no further security processing shall be done on this frame.

b

Let *m* be the output of step 4. If the security level requires encryption, set the octet string *UnsecuredNwkFrame* to the string *NwkHeader* || *m*. Otherwise, set the octet string *UnsecuredNwkFrame* to the string *NwkHeader* || *Payload₁*.
- 6

Set *FrameCount* to (*ReceivedFrameCount* + 1) and store both *FrameCount* and *SenderAddress* in the NIB. *UnsecuredNwkFrame* now represents the unsecured received network frame and security processing shall succeed. So as to never cause the storage of the frame count and address information to exceed the available memory, the memory allocated for incoming frame counters needed for NWK layer security shall be bounded by *M***N*, where *M* and *N* represent the cardinality of *nwkSecurityMaterialSet* and *nwkNeighborTable* in the NIB, respectively.
- 7

If the sequence number of the received frame belongs to a newer entry in the *nwkSecurityMaterialSet*, set the *nwkActiveKeySeqNumber* to the received sequence number.
- 8

If there is an entry in *nwkNeighborTable* in the NIB whose extended address matches *SenderAddress* and whose relationship field has value 0x05 (unauthenticated child), then set relationship field in that entry to the value 0x01 (child).

4.3.2 Secured NPDU Frame

The NWK layer frame format (see sub-clause 3.3.1) consists of a NWK header and NWK payload field. The NWK header consists of frame control and routing fields. When security is applied to an NPDU frame, the security bit in the NWK frame control field shall be set to 1 to indicate the presence of the auxiliary frame header. The format for the auxiliary frame header is given in sub-clause 4.5.1. The format of a secured NWK layer frame is shown in Figure 4.3. The auxiliary frame header is situated between the NWK header and payload fields.

Octets: Variable	14	Variable	
Original NWK header ([B3], Clause 7.1)	Auxiliary frame header	Encrypted payload	Encrypted message integrity code (MIC)
		Secure frame payload = output of CCM*	
Full NWK header		Secured NWK payload	

Figure 4.3 Secured NWK Layer Frame Format

4.3.3 Security-Related NIB Attributes

The NWK PIB contains attributes that are required to manage security for the NWK layer. Each of these attributes can be read and written using the NLME-GET.request and NLME-SET.request primitives, respectively. The security-related attributes contained in the NWK PIB are presented in Tables 4.1 through 4.3.

Table 4.1 NIB Security Attributes

Attribute	Identifier	Type	Range	Description	Default
<i>nwkSecurityLevel</i>	0xa0	Octet	0x00-07	The security level for outgoing and incoming NWK frames; the allowable security level identifiers are presented in Table 4.40.	0x05
<i>nwkSecurity-MaterialSet</i>	0xa1	A set of 0, 1, or 2 network security material descriptors (see Table 4.2)	Variable	Set of network security material descriptors capable of maintaining an active and alternate network key.	-
<i>nwkActiveKey SeqNumber</i>	0xa2	Octet	0x00-0xFF	The sequence number of the active network key in <i>nwkSecurityMaterialSet</i> .	0x00

Table 4.1 NIB Security Attributes (Continued)

Attribute	Identifier	Type	Range	Description	Default
<i>nwkAllFresh</i>	0xa3	Boolean	TRUE | FALSE	Indicates whether incoming NWK frames must be all checked for freshness when the memory for incoming frame counts is exceeded.	TRUE
<i>nwkSecureAllFrames</i>	0xa5	Boolean	TRUE | FALSE	Indicates whether security shall be applied to incoming and outgoing NWK data frames. If set to 0x01, security processing shall be applied to all incoming and outgoing frames except data frames destined for the current device that have the security sub-field of the frame control field set to 0. If this attribute has a value of 0x01, the NWK layer shall not relay frames that have the security sub-field of the frame control field set to 0. The SecurityEnable parameter of the NLDE-DATA.request primitive shall override the setting of this attribute.	TRUE

Table 4.2 Elements of the Network Security Material Descriptor

Name	Type	Range	Description	Default
KeySeqNumber	Octet	0x00-0xFF	A sequence number assigned to a network key by the Trust Center and used to distinguish network keys for purposes of key updates, and incoming frame security operations.	00
OutgoingFrameCounter	Ordered set of 4 octets.	0x00000000-0xFFFFFFFF F	Outgoing frame counter used for outgoing frames.	0x00000000
IncomingFrameCounterSet	Set of incoming frame counter descriptor values. See Table 4.3.	Variable	Set of incoming frame counter values and corresponding device addresses.	Null set
Key	Ordered set of 16 octets.	-	The actual value of the key.	-
KeyType	Octet	0x00 - 0xff	The type of the key. 0x01 = standard 0x05 = high security All other values are reserved.	0x01

Table 4.3 Elements of the Incoming Frame Counter Descriptor

Name	Type	Range	Description	Default
SenderAddress	Device address	Any valid 64-bit address	Extended device address.	Device specific
IncomingFrameCounter	Ordered set of 4 octets	0x00000000-0xFFFFFFFF	Incoming frame counter used for incoming frames.	0x00000000

4.4 APS Layer Security

The APS layer is responsible for the processing steps needed to securely transmit outgoing frames, securely receive incoming frames, and securely establish and manage cryptographic keys. Upper layers control the management of cryptographic keys by issuing primitives to the APS layer.

Table 4.4 lists the primitives available for key management and maintenance. Upper layers also determine which security level to use when protecting outgoing frames.

Table 4.4 The APS Layer Security Primitives

APSME Security Primitives	Request	Confirm	Indication	Response	Description
APSME-ESTABLISH-KEY	sub-clause 4.4.2.1	sub-clause 4.4.2.2	sub-clause 4.4.2.3	sub-clause 4.4.2.4	Establishes a link key with another ZigBee device using the SKKE method.
APSME-TRANSPORT-KEY	sub-clause 4.4.3.1	-	sub-clause 4.4.3.2	-	Transports security material from one device to another.
APSME-UPDATE-DEVICE	sub-clause 4.4.4.1	-	sub-clause 4.4.4.2	-	Notifies the Trust Center when a new device has joined, or an existing device has left the network.
APSME-REMOVE-DEVICE	sub-clause 4.4.5.1	-	sub-clause 4.4.5.2	-	Used by the Trust Center to notify a router that one of the router's child devices should be removed from the network.
APSME-REQUEST-KEY	sub-clause 4.4.6.1	-	sub-clause 4.4.6.2	-	Used by a device to request that the Trust Center send an application master key or active network key.
APSME-SWITCH-KEY	sub-clause 4.4.7.1	-	sub-clause 4.4.7.2	-	Used by the Trust Center to tell a device to switch to a new network key.
APSME-AUTHENTICATE	sub-clause 4.4.8.1	sub-clause 4.4.8.2	sub-clause 4.4.8.3	-	Used by two devices to mutually authenticate each other.

4.4.1 Frame Security

The detailed steps involved in security processing of outgoing and incoming APS frames are described in sub-clauses 4.4.1.1 and 4.4.1.2, respectively.

4.4.1.1 Security Processing of Outgoing Frames

If the APS layer has a frame, consisting of a header *ApsHeader* and payload *Payload*, that needs security protection and *nwkSecurityLevel* > 0, it shall apply security as follows:

- 1 Obtain the security material and key identifier *KeyIdentifier* using the following procedure. If security material or key identifier cannot be determined, then security processing shall fail and no further security processing shall be done on this frame.
 - a If the frame is a result of a APSDE-DATA.request primitive:
 - i If the TxOptions parameter specifies that the active network key is required to secure the data frame, then security material shall be obtained by using the *nwkActiveKeySeqNumber* from the NIB to retrieve the active network key, outgoing frame counter, and sequence number from the *nwkSecurityMaterialSet* attribute in the NIB. *KeyIdentifier* shall be set to '01' (that is, the active network key).
 - ii Otherwise, the security material associated with the destination address of the outgoing frame shall be obtained from the *apsDeviceKeyPairSet* attribute in the AIB. *KeyIdentifier* shall be set to '00' (that is, a data key).
 - b If the frame is a result of an APS command that requires securing.
 - i First, an attempt shall be made to retrieve the security material associated with the destination address of the outgoing frame from the *apsDeviceKeyPairSet* attribute in the AIB. For all cases except transport-key commands, *KeyIdentifier* shall be set to '00' (that is, a data key). For the case of transport-key commands, *KeyIdentifier* shall be set to '02' (that is, the key-transport key) when transporting a network key and shall be set to '03' (that is, the key-load key) when transporting an application link key, application master key, or Trust Center master key. See sub-clause 4.5.3 for a description of the key-transport and key-load keys.
 - ii If the first attempt fails, then security material shall be obtained by using the *nwkActiveKeySeqNumber* from the NIB to retrieve the active network key, outgoing frame counter, and sequence number from the *nwkSecurityMaterialSet* attribute in the NIB. *KeyIdentifier* shall be set to '01' (that is, the active network key).

- 2 If *KeyIdentifier* is 01 (that is, the active network key), the APS layer shall first verify that the NWK layer is not also applying security. If the NWK layer is applying security, then the APS layer shall not apply any security. The APS layer can determine that the NWK layer is applying security by verifying that the value of the *nwkSecureAllFrames* attribute of the NIB has a value of TRUE and the *nwkSecurityLevel* NIB attribute has a non-zero value.
- 3 Extract the outgoing frame counter (and, if *KeyIdentifier* is 01, the key sequence number) from the security material obtained from step 1. If the outgoing frame counter has as its value the 4-octet representation of the integer $2^{32}-1$, or if the key cannot be obtained, security processing shall fail and no further security processing shall be done on this frame.
- 4 Obtain the security level from the *nwkSecurityLevel* attribute from the NIB.
- 5 Construct auxiliary header *AuxiliaryHeader* (see sub-clause 4.5.1). The security control field shall be set as follows:
 - a The security level sub-field shall be the security level obtained from step 4.
 - i The key identifier sub-field shall be set to *KeyIdentifier*.
 - ii The extended nonce sub-field shall be set as follows: If the TxOptions bit for include extended nonce is set (0x10) then the extended nonce sub-field shall be set to 1. Otherwise it shall be set to 0.
 - a If the extended nonce sub-field is set to 1, then set the source address field to the 64-bit extended address of the local device.³⁷
 - b The frame counter field shall be set to the outgoing frame counter from step 3.
 - c If *KeyIdentifier* is 01, the key sequence number field shall be present and set to the key sequence number from step 3. Otherwise, the key sequence number field shall not be present.
- 6 Execute the CCM* mode encryption and authentication operation, as specified in sub-clause A.2, with the following exceptions:
 - a The parameter *M* shall be obtained from Table 4.40 corresponding to the security level from step 3.
 - b The bit string *Key* shall be the key obtained from step 1.
 - c The nonce *N* shall be the 13-octet string constructed using the security control and frame counter fields from step 5 and the 64-bit extended address of the local device (see sub-clause 4.5.2.2).

37. CCB 1184

- d If the security level requires encryption, the octet string *a* shall be the string *ApsHeader* || *AuxiliaryHeader* and the octet string *m* shall be the string *Payload*. Otherwise, the octet string *a* shall be the string *ApsHeader* || *AuxiliaryHeader* || *Payload* and the octet string *m* shall be a string of length zero.
- 7 If the CCM* mode invoked in step 6 outputs “invalid”, security processing shall fail and no further security processing shall be done on this frame.
- 8 Let *c* be the output from step 6. If the security level requires encryption, the secured outgoing frame shall be *ApsHeader* || *AuxiliaryHeader* || *c*, otherwise the secured outgoing frame shall be *ApsHeader* || *AuxiliaryHeader* || *Payload* || *c*.
- 9 If the secured outgoing frame size will result in the MSDU being greater than *aMaxMACFrameSize* octets (see IEEE Std. 802.15.4 802 [B1]), security processing shall fail and no further security processing shall be done on this frame.
- 10 The outgoing frame counter from step 3 shall be incremented and stored in the appropriate location(s) of the NIB, AIB, and MAC PIB corresponding to the key that was used to protect the outgoing frame.
- 11 Over-write the security level sub-field of the security control field with the 3-bit all-zero string '000'.

4.4.1.2 Security Processing of Incoming Frames

If the APS layer receives a secured frame (consisting of a header *ApsHeader*, auxiliary header *AuxiliaryHeader*, and payload *SecuredPayload*) as indicated by the security sub-field of the APS header frame control field it shall perform security processing as follows:

- 1 Determine the sequence number *SequenceNumber*, key identifier *KeyIdentifier*, and received frame counter value *ReceivedFrameCounter* from the auxiliary header *AuxiliaryHeader*. If *ReceivedFrameCounter* is the 4-octet representation of the integer $2^{32}-1$, security processing shall fail and no further security processing shall be done on this frame.
- 2 Determine the source address *SourceAddress* from the address-map table in the NIB, using the source address in the APS frame as the index. If the source address is incomplete or unavailable, security processing shall fail and no further security processing shall be done on this frame.
- 3 Obtain the appropriate security material in the following manner. If the security material cannot be obtained, security processing shall fail and no further security processing shall be done on this frame.

- a If *KeyIdentifier* is '00' (i.e., a data key), the security material associated with the *SourceAddress* of the incoming frame shall be obtained from the *apsDeviceKeyPairSet* attribute in the AIB.
 - b If *KeyIdentifier* is '01' (i.e., a network key), the security material shall be obtained by matching *SequenceNumber* to the sequence number of any key in the *nwkSecurityMaterialSet* attribute in the NIB.
 - c If *KeyIdentifier* is '02' (i.e., a key-transport key), the security material associated with the *SourceAddress* of the incoming frame shall be obtained from the *apsDeviceKeyPairSet* attribute in the AIB; the key for this operation shall be derived from the security material as specified in sub-clause 4.5.3 for the key-transport key.
 - d If *KeyIdentifier* is '03' (i.e., a key-load key), the security material associated with the *SourceAddress* of the incoming frame shall be obtained from the *apsDeviceKeyPairSet* attribute in the AIB and the key for this operation shall be derived from the security material as specified in sub-clause 4.5.3 for the key-load key.
- 4 If the *apsLinkKeyType* of the associated link key is 0x00 (unique) and there³⁸ is an incoming frame count *FrameCount* corresponding to *SourceAddress* from the security material obtained in step 3 and if *ReceivedFrameCount* is less than *FrameCount*, security processing shall fail and no further security processing shall be done on this frame.
- 5 Determine the security level *SecLevel* as follows. If the frame type sub-field of the frame control field of *ApsHeader* indicates an APS data frame, then *SecLevel* shall be set to the *nwkSecurityLevel* attribute in the NIB. Overwrite the security level sub-field of the security control field in the *AuxiliaryHeader* with the value of *SecLevel*.
- 6 Execute the CCM* mode decryption and authentication checking operation as specified in sub-clause A.3, with the following instantiations:
- a The parameter *M* shall be obtained from Table 4.40 corresponding to the security level from step 5.
 - b The bit string *Key* shall be the key obtained from step 3.
 - c The nonce *N* shall be the 13-octet string constructed using the security control and frame counter fields from *AuxiliaryHeader*, and *SourceAddress* from step 2 (see sub-clause 4.5.2.2).
 - d Parse the octet string *SecuredPayload* as *Payload₁* || *Payload₂*, where the rightmost string *Payload₂* is an *M*-octet string. If this operation fails,

38. CCB 1313

security processing shall fail and no further security processing shall be done on this frame.

- e If the security level requires encryption, the octet string *a* shall be the string *ApsHeader* || *AuxiliaryHeader* and the octet string *c* shall be the string *SecuredPayload*. Otherwise, the octet string *a* shall be the string *ApsHeader* || *AuxiliaryHeader* || *Payload₁* and the octet string *c* shall be the string *Payload₂*.

7 Return the results of the CCM* operation:

- a If the CCM* mode invoked in step 6 outputs “invalid”, security processing shall fail and no further security processing shall be done on this frame.
- b Let *m* be the output of step 6. If the security level requires encryption, set the octet string *UnsecuredApsFrame* to the string *ApsHeader* || *m*. Otherwise, set the octet string *UnsecuredApsFrame* to the string *ApsHeader* || *Payload*.

8 Set *FrameCount* to (*ReceivedFrameCount* + 1) and store both *FrameCount* and *SourceAddress* in the appropriate security material as obtained in step 3. If storing this frame count and address information will cause the memory allocation for this type of information to be exceeded, and the *nwkAllFresh* attribute in the NIB is TRUE, then security processing shall fail and no further security processing shall be done on this frame. Otherwise, security processing shall succeed.

9 If the sequence number of the received frame belongs to a newer entry in the *nwkSecurityMaterialSet* then the *nwkActiveKeySeqNumber* shall be set to received sequence number.

4.4.1.3 Security Processing of APS Commands

A device that is not the trust center that receives an APS command shall determine if the message was sent by the trust center. If the message was not sent by the trust center then it shall discard the message and no further processing shall be done.

If the message was sent by the trust center, the device shall then consult the AIB attribute *apsLinkKeyType* associated with the sending device to determine if the

key is a unique link key or global link key. It shall then consult Table 4.5 to determine the policy that shall be used.

Table 4.5 Security Policy for Accepting APS Commands

APS Command	Unique Link Key (0x00)	Global Link Key (0x01)
SKKE Commands (0x01 – 0x04)	APS encryption not required	APS encryption not required
Transport Key (0x05)	APS encryption is required as per device policy (see sub-clause 4.4.1.5)	APS encryption is required as per device policy (see sub-clause 4.4.1.5)
Update Device (0x06)	APS encryption required	APS encryption not required
Remove Device (0x07)	APS encryption required	APS encryption required
Request Key (0x08)	APS encryption required Trust Center Policy may further restrict, see sub-clause 4.4.1.5	APS encryption not required
Trust Center Policy may further restrict, see section 4.4.1.5		
Switch Key (0x09)	APS encryption not required	APS encryption not required
Entity Authentication (0x0A – 0x0D)	APS encryption not required	APS encryption not required
Tunnel Data (0x0E)	APS encryption not required	APS encryption not required

Upon reception of an APS command that does not have APS encryption but APS encryption is required by Table 4.5, the device shall drop the message and no further processing shall take place. If APS encryption is not required for the command but the received message has APS encryption, the receiving device shall accept and process the message. Accepting additional security on messages is required to support legacy devices in the field.

In order to support backwards compatibility with devices in the field, provisions will also be added for new devices to insure they can interoperate with the existing devices and their legacy requirements for APS encryption.

Table 4.6 Security Policy for Sending APS Commands

APS Command	Unique Trust Center Link Key	Global Trust Center Link Key
SKKE Commands (0x01 – 0x04)	APS encryption shall not be used	APS encryption shall not be used
Transport Key (0x05)	APS encryption may be optionally used. See sub-clause 4.4.1.5	APS encryption may be optionally used. See sub-clause 4.4.1.5
Update Device (0x06)	APS encryption shall be used.	APS encryption shall be conditionally used as per sub-clause 4.4.1.4.
Remove Device (0x07)	APS encryption shall be used	APS encryption shall be used
Request Key (0x08)	APS encryption shall be used	APS encryption shall not be used
Switch Key (0x09)	APS encryption may be used	APS encryption shall not be used
Entity Authentication (0x0A – 0x0D)	APS encryption shall not be used	APS encryption shall not be used
Tunnel Data (0x0E)	APS encryption shall not be used	APS encryption shall not be used

When the local device will transmit an APS command, it shall consult Table 4.6 above to determine the appropriate behavior. If APS encryption is required to be used, then the device shall APS encrypt the command prior to sending the message. If APS encryption is deemed not to be used, the device shall NOT APS encrypt the message prior to sending the message. Conditional encryption of APS commands shall follow the procedure as defined by sub-clause 4.4.1.4.

4.4.1.4 Conditional Encryption of APS Commands

Devices that have already been released in the field may have requirements on when APS encryption must or must not be used. The following procedure shall be undertaken as required by Table 4.6 to insure correct operation with those devices.

When sending an APS command that must be conditionally encrypted, the device shall send the APS command with or without APS encryption according to the requirements of the receiving device. If the receiving device is capable of accepting APS encrypted APS commands then the sending device may send APS encrypted APS commands. If the receiving device is not capable of receiving APS

encrypted APS commands then the sending device may send APS commands without APS encryption.

It is left up to the implementers to determine whether or not the receiving device is capable of receiving an APS command with APS encryption. A device may simply send two copies of the APS command, one with APS encryption and one without, in order to satisfy the requirements of interoperability with existing devices.

Conditional encryption of APS commands shall only apply when the *apsLinkKeyType* with receiving device is set to global link key (0x01).

4.4.1.5 Acceptance of Commands Based on Security Policy

There are two commands that may be conditionally accepted based on the local security policies in place on the device.

The APS Request key command requires APS encryption based on Table 4.5. However the trust center may apply additional security policies based on the profile in use, or other additional factors. A trust center that disallows requesting a key may do so based on the type being requested, or it may disallow all requests. In this case the trust center is permitted to drop the APS request key command and not respond.

The APS transport key command may be sent with or without APS encryption. The decision to do so is based on the trust center's security policies. The trust center may deem it acceptable to send a key without APS encryption based on the type, or simply choose to send all requests unencrypted.

Conversely, a device receiving an APS transport key command may choose whether or not APS encryption is required. This is most often done during initial joining. For example, during joining a device that has no preconfigured link key would only accept unencrypted transport key messages, while a device with a preconfigured link key would only accept a transport key APS encrypted with its preconfigured key.

The application profile implemented by the device may dictate the policies in place for these commands.³⁹

4.4.2 Key-Establishment Services

The APSME provides services that allow two devices to mutually establish a link key. Initial trust information (for example, a master key) must be installed in each device prior to running the key establishment protocol (see sub-clause 4.4.3 for mechanisms to provision initial trust information).

39. CCB 1313

4.4.2.1 APSME-ESTABLISH-KEY.request

The APSME-ESTABLISH-KEY request primitive is used for initiating a key-establishment protocol. This primitive can be used when there is a need to securely communicate with another device.

One device will act as an initiator device, and the other device will act as the responder. The initiator shall start the key-establishment protocol by issuing:

- The APSME-ESTABLISH-KEY.request with parameters indicating the address of the responder device.
- An indication of which key-establishment protocol to use (currently SKKE).

4.4.2.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface

APSME-ESTABLISH-KEY.request	{
	ResponderAddress,
	UseParent,
	ResponderParentAddress,
	KeyEstablishmentMethod
	}

Table 4.7 specifies the parameters for the APSME-ESTABLISH-KEY.request primitive.

Table 4.7 APSME-ESTABLISH-KEY.request Parameters

Parameter Name	Type	Valid Range	Description
Responder-Address	Device Address	Any valid 64-bit address	The extended 64-bit address of the responder device.

Table 4.7 APSME-ESTABLISH-KEY.request Parameters (Continued)

UseParent	Boolean	TRUE | FALSE	This parameter indicates if the responder's parent shall be used to forward messages between the initiator and responder devices: TRUE: Use parent FALSE: Do not use parent
Responder-ParentAddress	Device Address	Any valid 64-bit address	If UseParent is TRUE, then the ResponderParentAddress parameter shall contain the extended 64-bit address of the responder's parent device. Otherwise, this parameter is not used and need not be set.
KeyEstablishment-Method	Integer	0x00 - 0x03	The requested key-establishment method shall be one of the following: 0x00 = SKKE method 0x01-0x03 = reserved

4.4.2.1.2 When Generated

A higher layer on an initiator device shall generate this primitive when it requires a link key to be established with a responder device. If the initiator device wishes to use the responder's parent as a liaison (for NWK security purposes), it shall set the UseParent parameter to TRUE and shall set the ResponderParentAddress parameter to the 64-bit extended address of the responder's parent.

4.4.2.1.3 Effect on Receipt

The receipt of an APSME-ESTABLISH_KEY.request primitive, with the KeyEstablishmentMethod parameter equal to SKKE, shall cause the APSME to execute the SKKE protocol, as described in sub-clause 4.4.2.6. The local APSME shall act as the initiator of this protocol, the APSME indicated by the ResponderAddress parameter shall act as the responder of this protocol, and the UseParent parameter will control whether the messages are sent indirectly via the responder's parent device given by the ResponderParentAddress parameter.

4.4.2.2 APSME-ESTABLISH-KEY.confirm

This primitive is issued to the ZDO upon completion or failure of a key-establishment protocol.

4.4.2.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-ESTABLISH-KEY.confirm	{
	Address,
	Status
	}

Table 4.8 specifies the parameters of the APSME-ESTABLISH-KEY.confirm primitive. Table 4.12 gives a description of some codes that can be returned in the Status parameter of this primitive. In addition to these codes, if, when sending one of the protocol messages, an NLDE-DATA.confirm primitive with a Status parameter set to a value other than SUCCESS is issued, the Status parameter of the APSME-ESTABLISH-KEY.confirm primitive shall be set to that received from the NWK layer.

Table 4.8 APSME-ESTABLISH-KEY.confirm Parameters

Name	Type	Valid Range	Description
Address	Device Address	Any valid 64-bit address.	The extended 64-bit address of the device with which the key-establishment protocol was executed.
Status	Enumeration	Value given by Table 4.12 or any status value returned from the NLDE-DATA.confirm primitive.	This parameter indicates the final status of the key-establishment protocol.

4.4.2.2.2 When Generated

The APSME in both the responder and initiator devices shall issue this primitive to the ZDO upon completion of a key-establishment protocol.

4.4.2.2.3 Effect on Receipt

If key establishment is successful, the AIB of the initiator and responder shall be updated with the new link key and the initiator shall be able to securely communicate with the responder. If the key establishment was not successful, then the AIB shall not be changed.

4.4.2.3 APSME-ESTABLISH-KEY.indication

The APSME in the responder shall issue this primitive to its ZDO when it receives an initial key-establishment message (for example, an SKKE-1 frame) from an initiator.

4.4.2.3.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-ESTABLISH-KEY.indication	{
	InitiatorAddress,
	KeyEstablishmentMethod
	}

Table 4.9 specifies the parameters of the APSME-ESTABLISH-KEY.indication primitive.

Table 4.9 APSME-ESTABLISH-KEY.indication Parameters

Name	Type	Valid Range	Description
InitiatorAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the initiator device.
KeyEstablishmentMethod	Integer	0x00 - 0x03	The requested key-establishment method shall be one of the following: 0x00 = SKKE method 0x01-0x03 = reserved

4.4.2.3.2 When Generated

The APSME in the responder device shall issue this primitive to the ZDO when a request to start a key-establishment protocol (for example, an SKKE-1 frame) is received from an initiator device and a master key associated with the initiator is present in the AIB.

4.4.2.3.3 Effect on Receipt

Upon receiving the APSME-ESTABLISH-KEY.indication primitive, the ZDO may use the KeyEstablishmentMethod and InitiatorAddress parameters to determine whether to establish a key with the initiator. The ZDO shall respond using the APSME-ESTABLISH-KEY.response primitive.

4.4.2.4 APSME-ESTABLISH-KEY.response

The ZDO of the responder device shall use the APSME-ESTABLISH-KEY.response primitive to respond to an APSME-ESTABLISH-KEY.indication primitive. The ZDO determines whether to continue with the key establishment or halt it. This decision is indicated in the Accept parameter of the APSME-ESTABLISH-KEY.response primitive.

4.4.2.4.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

```

APSME-ESTABLISH-KEY.response      {
                                   InitiatorAddress,
                                   Accept
                                   }
    
```

Table 4.10 specifies the parameters of the APSME-ESTABLISH-KEY.response primitive.

Table 4.10 APSME-ESTABLISH-KEY.response Parameters

Name	Type	Valid Range	Description
InitiatorAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that initiated key establishment
Accept	Boolean	TRUE | FALSE	This parameter indicates the response to an initiator's request to execute a key-establishment protocol. The response shall be either: TRUE = Accept FALSE = Reject

4.4.2.4.2 When Generated

The APSME-ESTABLISH-KEY.response primitive shall be generated by the ZDO and provided to the APSME following a request from an initiator device to start a key-establishment protocol (that is, after receipt of an APSME-ESTABLISH-KEY.indication). This primitive provides the responder's ZDO with an opportunity to determine whether to accept or reject a request to establish a key with a given initiator.

In addition to any other criterion for this decision, the responder's ZDO shall check the permissions configuration table as detailed in sub-clause 4.6.3.8.

4.4.2.4.3 Effect on Receipt

If the Accept parameter is TRUE, then the APSME of the responder will attempt to execute the key establishment protocol indicated by the KeyEstablishmentMethod parameter. If KeyEstablishmentMethod is equal to SKKE, the APSME shall execute the SKKE protocol, described in sub-clause 4.4.2.6. The local APSME shall act as the responder of this protocol and the APSME indicated by the InitiatorAddress parameter shall act as the initiator of this protocol. If the Accept parameter is FALSE, the local APSME shall halt and erase all intermediate data pertaining to the pending key-establishment protocol.

If the UseParent sub-parameter of the TransportKeyData parameter and the *nwkSecureAllFrame* NIB attribute are both TRUE, the command frame shall be embedded in a tunnel command frame as described in sub-clause 4.6.3.7 and the tunnel command shall be sent in place of the transport key command.

4.4.2.5 Data Service Message Sequence Chart

Figure 4.4 illustrates the sequence of primitives necessary for a successful key establishment between two devices.

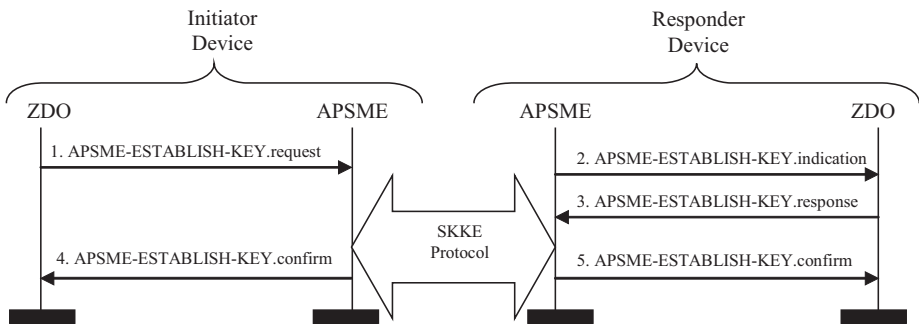


Figure 4.4 Sequence Chart for Successful APSME-ESTABLISH-KEY Primitives

4.4.2.6 The SKKE Protocol

The APSME on the initiator and responder execute the symmetric-key key-agreement scheme instantiated in sub-clause B.2.1 and specified in sub-clause B.1. The shared key (as specified in sub-clause B.1 prerequisite step 2), shall be the master key shared between the initiator and responder devices as obtained from the appropriate master key element in the *apsDeviceKeyPairSet* attribute in the AIB. The messages sent during the scheme specified in sub-clause B.1 shall be assigned to the frame names given in Table 4.11. The formats for these SKKE frames are given in sub-clause 4.4.9.1. The initiator device is responsible for sending the SKKE-1 and SKKE-3 frames and the responder device is responsible for sending the SKKE-2 and SKKE-4 frames. Additionally, if the UseParent parameter of the APSME-ESTABLISH-KEY.request primitive is TRUE, the responder device’s parent (as indicated by the ResponderParentAddress parameter of the APSME-ESTABLISH-KEY.request primitive) shall act as a liaison and forward messages between the initiator and responder devices.

During the key-establishment scheme, if the responder or initiator device detects any error condition listed in Table 4.12, the scheme shall be aborted and the local APSME shall issue the APSME-ESTABLISH-KEY.confirm primitive with the Status parameter set as indicated in Table 4.12. If no error conditions occur (that

is, the key-agreement scheme outputs “valid”), then the initiator and responder shall consider the derived key (that is, *KeyData*) as their newly shared link key. Both the initiator and responder shall update or add this link key to their AIB, set the corresponding incoming and outgoing frame counts to zero, and issue the APSME-ESTABLISH-KEY.confirm primitive with the Status parameter set to SUCCESS.

Table 4.11 Mapping of Frame Names to Symmetric-Key Key Agreement Scheme Messages

Frame Name	Description	Reference
SKKE-1	Sent by initiator during action step 1 (sub-clause B.7.1)	sub-clause 4.4.2.6.2
SKKE-2	Sent by responder during action step 2 (sub-clause B.7.2)	sub-clause 4.4.2.6.3
SKKE-3	Sent by initiator during action step 8 (sub-clause B.7.1)	sub-clause 4.4.2.6.4
SKKE-4	Sent by responder during action step 9 (sub-clause B.7.2)	sub-clause 4.4.2.6.5

Table 4.12 Mapping of Symmetric-Key Key Agreement Error Conditions to Status Codes

Status Description	Status Code	Value
No errors occur.	SUCCESS	0x00
An invalid parameter was input to one of the key establishment primitives.	INVALID_PARAMETER	0x01
No master key is available.	NO_MASTER_KEY	0x02
Challenge is invalid: Initiator during action step 3 (sub-clause B.7.1) Responder during action step 3 (sub-clause B.7.2)	INVALID_CHALLENGE	0x03
SKG outputs invalid: Initiator during action step 4 (sub-clause B.7.1) Responder during action step 3 (sub-clause B.7.2)	INVALID_SKG	0x04
MAC transformation outputs invalid: Initiator during action step 8 (sub-clause B.7.1) Responder during action step 10 (sub-clause B.7.2)	INVALID_MAC	0x05
Tag checking transformation outputs invalid: Initiator during action step 12 (sub-clause B.7.1) Responder during action step 8 (sub-clause B.7.2)	INVALID_KEY	0x06
Either the initiator or responder waits for the next expected incoming message for time greater than the <i>apsSecurityTimeOutPeriod</i> attribute of the AIB.	TIMEOUT	0x07
Either the initiator or responder receives an SKKE frame out of order.	BAD_FRAME	0x08

4.4.2.6.1 Generating and Sending the Initial SKKE-1 Frame

The SKKE protocol begins with the initiator device sending an SKKE-1 frame. The SKKE-1 command frame shall be constructed as specified in sub-clause 4.4.9.1.

If the UseParent parameter of the APSME-ESTABLISH-KEY.request primitive is FALSE, the initiator device shall begin the protocol by sending this SKKE-1 frame directly to the responder device (as indicated by the ResponderAddress parameter of the APSME-ESTABLISH-KEY.request primitive). Otherwise, the initiator device shall begin the protocol by sending this SKKE-1 frame to the responder device’s parent (as indicated by the ResponderParentAddress parameter of the APSME-ESTABLISH-KEY.request primitive). The SKKE-1 frame shall be sent using the NLDE-DATA.request primitive with NWK layer security set to the default NWK layer security level.

4.4.2.6.2 On Receipt of the SKKE-1 Frame

If the responder address field of the SKKE-1 frame does not equal the local device address, the APSME shall perform the following steps:

- 1 If the device given by the responder address field is not a child of the local device, the SKKE-1 frame shall be discarded.
- 2 Otherwise, the APSME of the local device shall send the SKKE-1 frame to the responder device using the NLDE-DATA.request primitive with:
 - The DestAddr parameter set to the 16-bit address corresponding to the 64-bit address in the responder address field of the SKKE-1 frame.
 - The DiscoverRoute parameter set to 0x01.
 - The SecurityEnable parameter set to FALSE.

Otherwise, the APSME shall perform the following steps:

If the device does not have a master key corresponding to the initiator address field:

- 1 the SKKE-1 frame shall be discarded and the APSME-ESTABLISH-KEY.confirm primitive shall be issued with the Status parameter set to NO_MASTER_KEY (see Table 4.12). The APSME shall halt processing for this SKKE protocol.
- 2 Otherwise, the APSME shall issue an APSME-ESTABLISH-KEY.indication primitive with the InitiatorAddress parameter set to the initiator address field of the SKKE-1 frame and the KeyEstablishmentMethod parameter set to 0 (that is, the SKKE protocol).
- 3 After issuing the APSME-ESTABLISH-KEY.indication primitive, and upon receipt of the corresponding APSME-ESTABLISH-KEY.response primitive, the APSME shall evaluate the InitiatorAddress and Accept parameters of the received APSME-ESTABLISH-KEY.response primitive. If the InitiatorAddress parameter is set to the initiator address of the SKKE-1 frame and the Accept parameter set to FALSE, the APSME shall halt the SKKE protocol and discard the SKKE-1 frame.

Otherwise:

- 1 The device shall construct an SKKE-2 frame as specified in sub-clause 4.4.9.1. If the source of the SKKE-1 frame indicates the same device as the initiator address field of the SKKE-1 frame, the device shall send this SKKE-2 frame directly to the initiator device using the NLDE-DATA.request primitive, with the DestAddr parameter set to the source of the SKKE-1 frame, the DiscoverRoute parameter set to 0x01, and the SecurityEnable parameter set to

TRUE. Otherwise, the device shall send the SKKE-2 frame to its parent using the NLDE-DATA.request primitive, with the DiscoverRoute parameter set to 0x01, and the SecurityEnable parameter set to FALSE.

4.4.2.6.3 On Receipt of the SKKE-2 Frame

If the initiator address field of the SKKE-2 frame does not equal the local device address, the APSME shall perform the following steps:

- 1 If the device indicated by the responder address field is not a child of the local device, the SKKE-2 frame shall be discarded.
- 2 Otherwise, the device shall send the SKKE-2 frame to the initiator device using the NLDE-DATA.request primitive with NWK layer set to the default level.

Otherwise, the device shall construct an SKKE-3 frame as specified in sub-clause 4.4.9.1. If the source of the SKKE-2 frame is the same as the responder address field of the SKKE-2 frame, the device shall send this SKKE-3 frame directly to the responder device. Otherwise, the device shall send the SKKE-3 frame to the responder's parent. The SKKE-3 frame shall be sent using the NLDE-DATA.request primitive with NWK layer security set to the default NWK layer security level.

4.4.2.6.4 On Receipt of the SKKE-3 Frame

If the responder address field of the SKKE-3 frame does not equal the local device address, the APSME shall perform the following steps:

- 1 If the responder address field of the SKKE-3 frame does not equal the local device address, the APSME shall perform the following steps:
 - i If the device given by the responder address field is not a child of the local device, the SKKE-3 frame shall be discarded.
 - ii Otherwise, the device shall send the SKKE-3 to the responder device using the NLDE-DATA.request primitive with NWK layer security disabled.
 - iii Otherwise, the device shall process the SKKE-3 data field and if the protocol was not a success it shall issue an APSME-ESTABLISH-KEY.confirm primitive with the Address parameter set to the initiator's address and the Status parameter set appropriately.
- 2 If, from the device's perspective, the protocol was a success, the device shall construct an SKKE-4 frame as specified in sub-clause 4.4.9.1. If the source of the SKKE-3 frame is the same as the initiator address field of the SKKE-3 frame, the device shall send this SKKE-4 frame directly to the initiator device using the NLDE-DATA.request primitive with NWK layer security set to the default level. Otherwise, the device shall send the SKKE-4 frame to its parent using the NLDE-DATA.request primitive with NWK layer security disabled.

Finally, the device shall issue an APSME-ESTABLISH-KEY.confirm primitive with the Address parameter set the initiator’s address and the Status parameter set to success.

4.4.2.6.5 On Receipt of the SKKE-4 Frame

If the initiator address field of the SKKE-4 frame does not equal the local device address, the APSME shall perform the following steps:

- 1 If the device given by the responder address field is not a child of the local device, the SKKE-4 frame shall be discarded.
- 2 Otherwise, the APSME of the local device shall send the SKKE-4 frame to the initiator device using the NLDE-DATA.request primitive with NWK layer set to the default level.

Otherwise, the APSME shall process the SKKE-4 frame and issue an APSME-ESTABLISH-KEY.confirm primitive with the Address parameter set to the responder’s address and the Status parameter set appropriately.

4.4.3 Transport-Key Services

The APSME provides services that allow an initiator to transport keying material to a responder. The different types of keying material that can be transported are shown in Tables 4.14 to 4.17.

4.4.3.1 APSME-TRANSPORT-KEY.request

The APSME-TRANSPORT-KEY.request primitive is used for transporting a key to another device.

4.4.3.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-TRANSPORT-KEY.request	{
	DestAddress,
	KeyType,
	TransportKeyData
	}

Table 4.13 specifies the parameters for the APSME-TRANSPORT-KEY.request primitive.

Table 4.13 APSME-TRANSPORT-KEY.request Parameters

Parameter Name	Type	Valid Range	Description
DestAddress	Device address	Any valid 64-bit address	The extended 64-bit address of the destination device.
KeyType	Integer	0x00 – 0x06	Identifies the type of key material that should be transported; see Table 4.14.
TransportKeyData	Variable	Variable	The key being transported along with identification and usage parameters. The type of this parameter depends on the KeyType parameter as follows: KeyType = 0x00 see Table 4.15 KeyType = 0x01 see Table 4.16 KeyType = 0x02 see Table 4.17 KeyType = 0x03 see Table 4.17 KeyType = 0x04 see Table 4.15 KeyType = 0x05 see Table 4.16

Table 4.14 KeyType Parameter of the Transport-Key Primitive

Enumeration	Value	Description
Trust Center master key	0x00	Indicates the key is a master key used to set up link keys between the Trust Center and another device.
Standard network key	0x01	Indicates that the key is a network key to be used in standard security mode and may be distributed using key-transport or a standard network key.
Application master key	0x02	Indicates the key is a master key used to set up link keys between two devices.
Application link key	0x03	Indicates the key is a link key used as a basis of security between two devices.
Unique Trust-Center link key	0x04	Indicates that the key is a link key used as a basis for security between the Trust Center and another device.
High-security network key	0x05	Indicates that the key is a unique, pair-wis ^a e network key to be used in high security mode and may be distributed using key-transport only.

a. CCB 1313

Table 4.15 TransportKeyData Parameter for a Trust Center Master Key or Link Key

Parameter Name	Type	Valid Range	Description
ParentAddress	Device address	Any valid 64-bit address	The extended 64-bit address of the parent of the destination device given by the DestAddress parameter.
Key	Set of 16 octets	Variable	The Trust Center master or link key.

Table 4.16 TransportKeyData Parameter for a Network Key

Parameter Name	Type	Valid Range	Description
KeySeqNumber	Octet	0x00-0xFF	A sequence number assigned to a network key by the Trust Center and used to distinguish network keys for purposes of key updates and incoming frame security operations.
NetworkKey	Set of 16 octets	Variable	The network key.
UseParent	Boolean	TRUE | FALSE	This parameter indicates if the destination device's parent shall be used to forward the key to the destination device: TRUE = Use parent FALSE = Do not use parent
ParentAddress	Device address	Any valid 64-bit address	If the UseParent is TRUE, then ParentAddress parameter shall contain the extended 64-bit address of the destination device's parent device; otherwise, this parameter is not used and need not be set.

Table 4.17 TransportKeyData Parameter for an Application Master or Link Key

Parameter Name	Type	Valid Range	Description
PartnerAddress	Device address	Any valid 64-bit address	The extended 64-bit address of the device that was also sent this master key.
Initiator	Boolean	TRUE | FALSE	This parameter indicates if the destination device of this master key requested it: TRUE = If the destination requested the key FALSE = Otherwise
Key	Set of 16 octets	Variable	The master or link key (as indicated by the KeyType parameter).

4.4.3.1.2 When Generated

The ZDO on an initiator device shall generate this primitive when it requires a key to be transported to a responder device.

4.4.3.1.3 Effect on Receipt

The receipt of an APSME-TRANSPORT-KEY.request primitive shall cause the APSME to create a transport-key command packet (see sub-clause 4.4.9.2).

If the KeyType parameter is 0x00 or 0x04 (that is, Trust Center master or link key), the key descriptor field of the transport-key command shall be set as follows:

- The key sub-field shall be set to the Key sub-parameter of the TransportKeyData parameter.
- The destination address sub-field shall be set to the DestinationAddress parameter.
- The source address sub-field shall be set to the local device address.

This command frame shall be security-protected as specified in sub-clause 4.4.1.1. Then, if security processing succeeds, it is sent to the device specified by the ParentAddress sub-parameter of the TransportKeyData parameter by issuing a NLDE-DATA.request primitive.

If the DestinationAddress parameter is all zeros, the secured command frame shall be unicast to any and all rx-off-when-idle children of the device. These unicasts shall be repeated until successful, or a subsequent APSME-TRANSPORT-KEY.request primitive with the KeyType parameter equal to 0x01 or 0x05 has been received, or a period of twice the recommended maximum polling interval has passed.

If the KeyType parameter is 0x01 or 0x05 (that is, a network key), the key descriptor field of the transport-key command shall be set as follows:

- The key sub-field shall be set to the Key sub-parameter of the TransportKeyData parameter.
- The sequence number sub-field shall be set to the KeySeqNumber sub-parameter of the TransportKeyData parameter.
- The destination address sub-field shall be set to the DestinationAddress parameter.
- The source address sub-field shall be set to the local device address.

This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified by the ParentAddress sub-parameter of the TransportKeyData parameter (if the UseParent sub-parameter of the TransportKeyData parameter is TRUE) or the DestinationAddress parameter (if the UseParent sub-parameter of the TransportKeyData parameter is FALSE) by issuing a NLDE-DATA.request primitive.

If the UseParent sub-parameter of the TransportKeyData parameter is FALSE, and there is an entry in *nwkNeighborTable* whose extended address matches the SenderAddress parameter and whose relationship field has value 0x05 (unauthenticated child), then the relationship field in that entry shall be set to the value 0x01 (child).

If the KeyType parameter is 0x02 or 0x03 (that is, an application master or link key), the key descriptor field of the transport-key command shall be set as follows:

- The key sub-field shall be set to the Key sub-parameter of the TransportKeyData parameter.
- The partner address sub-field shall be set to the PartnerAddress sub-parameter of the TransportKeyData parameter.
- The initiator sub-field shall be set 1 (if the Initiator sub-parameter of the TransportKeyData parameter is TRUE) or 0 (if the Initiator sub-parameter of the TransportKeyData parameter is FALSE).

This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified by the DestinationAddress parameter by issuing a NLDE-DATA.request primitive.

4.4.3.2 APSME-TRANSPORT-KEY.indication

The APSME-TRANSPORT-KEY.indication primitive is used to inform the ZDO of the receipt of keying material.

4.4.3.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-TRANSPORT-KEY.indication	{
	SrcAddress,
	KeyType,
	TransportKeyData
	}

Table 4.18 specifies the parameters of the APSME-TRANSPORT-KEY.indication primitive.

Table 4.18 APSME-TRANSPORT-KEY.indication Parameters

Name	Type	Valid Range	Description
SrcAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that is the original source of the transported key.
KeyType	Octet	0x00 – 0x06	Identifies the type of key material that was be transported; see Table 4.14.
TransportKeyData	Variable	Variable	The key that was transported along with identification and usage parameters. The type of this parameter depends on the KeyType parameter as follows: KeyType = 0x00 see Table 4.19 KeyType = 0x01 see Table 4.20 KeyType = 0x02 see Table 4.22 KeyType = 0x03 see Table 4.22 KeyType = 0x04 see Table 4.19 KeyType = 0x05 see Table 4.20

Table 4.19 TransportKeyData Parameter for a Trust Center Master or Link Key

Parameter Name	Type	Valid Range	Description
TrustCenter-MasterKey	Set of 16 octets	Variable	The Trust Center master key.

Table 4.20 TransportKeyData Parameter for a Network Key

Parameter Name	Type	Valid Range	Description
KeySeqNumber	Octet	0x00-0xFF	A sequence number assigned to a network key by the Trust Center and used to distinguish; network keys for purposes of key updates and incoming frame security operations.
NetworkKey	Set of 16 octets	Variable	The network key.

Table 4.21 TransportKeyData Parameter for an Application Master or Link Key

Parameter Name	Type	Valid Range	Description
PartnerAddress	Device address	Any valid 64-bit address	The extended 64-bit address of the device that was also sent this master key.
Key	Set of 16 octets	Variable	The master or link key (as indicated by the KeyType parameter).

4.4.3.2.2 When Generated

The APSME shall generate this primitive when it receives a transport-key command as specified in sub-clause 4.4.3.3.

4.4.3.2.3 Effect on Receipt

Upon receipt of this primitive, the ZDO is informed of the receipt of the keying material.

4.4.3.3 Upon Receipt of a Transport-Key Command

Upon receipt of a transport-key command, the APSME shall execute security processing as specified in, then check the key type sub-field.

Upon receipt of a secured transport-key command, the APSME shall check the key type sub-field. If the key type field is set to 0x02, 0x03, 0x04, or 0x05 (that is, application link or master key, Trust Center link key, or high-security network key) and the command was not secured using a Trust Center link key, the command shall be discarded. If the key type field is set to 0x01 (that is, standard network key) and the command was not secured using a Trust Center link key or the active network key, the command shall be discarded.

If the key type field is set to 0x02 or 0x03 (that is, application link or master key), the APSME shall issue the APSME-TRANSPORT-KEY.indication primitive with: the SrcAddress parameter set to the source of the key-transport command (as indicated by the NLDE-DATA.indication SrcAddress parameter), and the KeyType parameter set to the key type field. The TransportKeyData parameter shall be set as follows:

- The Key sub-parameter shall be set to the key field.
- The PartnerAddress sub-parameter shall be set to the partner address field.
- The Initiator parameter shall be set to TRUE, if the initiator field is 1. Otherwise it shall be set to 0.

If the key type field is set to 0x00, 0x01, 0x04, or 0x05 (that is, Trust Center master or link key, or a network key) and the destination field is equal to the local address, or if the key type field is set to 0x01 (that is, a standard network key), the destination field is the all-zero string, and the current network key type is equal to the value of the key type field, the APSME shall issue the APSME-TRANSPORT-KEY.indication primitive with the SrcAddress parameter set to the source address field of the key-transport command and the KeyType parameter set to the key type field. The TransportKeyData parameter shall be set as follows: the Key sub-parameter shall be set to the key field and, in the case of a network key (that is, the key type field is set to 0x01 or 0x05), the KeySeqNumber sub-parameter shall be set to the sequence number field.

If the key type field is set to 0x00 or 0x01 (that is, Trust Center master or link key or standard network key) and the destination address field is not equal to the local address, the APSME shall send the command to the address indicated by the destination address field by issuing the NLDE-DATA.request primitive with security disabled.

If the key type field is set to 0x01 (that is, the standard network key) and there is an entry in *nwkNeighborTable* whose extended address matches value of the destination address field and whose relationship field has value 0x05 (unauthenticated child), then the relationship field in that entry shall be set to the value 0x01 (child).

Upon receipt of a secured transport-key command with the key type field set to 0x01, if the destination field is all zeros and the source address field is set to the

value of *apsTrustCenterAddress*, the router shall attempt to unicast this transport-key command to any and all rx-off-when-idle children. The router shall continue to do so until successful, or until a subsequent transport-key command with the key type field set to 0x01 or 0x05 has been received, or until a period of twice the recommended maximum polling interval has passed.

Upon receipt of an unsecured transport-key command, the APSME shall check the key type sub-field. If the key type field is set to 0x00 (that is, a Trust Center master key), the destination address field is equal to the local address, and the device does not have a Trust Center master key and address (*i.e.*, the *apsTrustCenterAddress* in the AIB), then the APSME shall issue the APSME-TRANSPORT-KEY.indication primitive. If the key type field is set to 0x01 or 0x05 (that is, a network key), the destination address field is equal to the local address, and the device does not have a network key, then the APSME shall issue the APSME-TRANSPORT-KEY.indication primitive. If the key type field is set to 0x04 (*i.e.*, the Trust Center link key), the destination address field is equal to the local address, and the device does not have a Trust Center link key, then the APSME shall issue the APSME-TRANSPORT-KEY.indication primitive. If an APSME-TRANSPORT-KEY.indication primitive is issued, the SrcAddress parameter shall be set to the source address field of the key-transport command, and the KeyType parameter shall be set to the key type field. The TransportKeyData parameter shall be set as follows: the Key sub-parameter shall be set to the key field and, in the case of a network key (that is, the key type field is set to 0x01 or 0x05), the KeySeqNumber sub-parameter shall be set to the sequence number field.

4.4.4 Update Device Services

The APSME provides services that allow a device (for example, a router) to inform another device (for example, a Trust Center) that a third device has changed its status (for example, joined or left the network).

4.4.4.1 APSME-UPDATE-DEVICE.request

The ZDO shall issue this primitive when it wants to inform a device (for example, a Trust Center) that another device has a status that needs to be updated (for example, the device joined or left the network).

4.4.4.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-UPDATE-DEVICE.request	{
	DestAddress,
	DeviceAddress,
	Status,
	DeviceShortAddress
	}

Table 4.22 specifies the parameters for the APSME-UPDATE-DEVICE.request primitive.

Table 4.22 APSME-UPDATE-DEVICE.request Parameters

Parameter Name	Type	Valid Range	Description
DestAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that shall be sent the update information.
DeviceAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device whose status is being updated.
Status	Integer	0x00 – 0x07	Indicates the updated status of the device given by the DeviceAddress parameter: 0x00 = Standard device secured rejoin 0x01 = Standard device unsecured join 0x02 = Device left 0x03 = Standard device trust center rejoin 0x04 = High security device secured rejoin 0x05 = High security device trust center join 0x06 = Reserved 0x07 = High security device trust center rejoin
DeviceShortAddress	Network address	0x0000 - 0xffff	The 16-bit network address of the device whose status is being updated.

4.4.4.1.2 When Generated

The ZDO (for example, on a router or ZigBee coordinator) shall initiate the APSME-UPDATE-DEVICE.request primitive when it wants to send updated device information to another device (for example, the Trust Center).

4.4.4.1.3 Effect on Receipt

Upon receipt of the APSME-UPDATE-DEVICE.request primitive, the device shall first create an update-device command frame (see sub-clause 4.4.9.3). The device address field of this command frame shall be set to the DeviceAddress parameter, the status field shall be set according to the Status parameter, and the device short address field shall be set to the DeviceShortAddress parameter. This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified in the DestAddress parameter by issuing a NLDE-DATA.request primitive.

4.4.4.2 APSME-UPDATE-DEVICE.indication

The APSME shall issue this primitive to inform the ZDO that it received an update-device command frame.

4.4.4.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-UPDATE-DEVICE.indication	{
	SrcAddress,
	DeviceAddress,
	Status,
	DeviceShortAddress
	}

Table 4.23 specifies the parameters for the APSME-UPDATE-DEVICE.indication primitive.

Table 4.23 APSME-UPDATE-DEVICE.indication Parameters

Parameter Name	Type	Valid Range	Description
SrcAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device originating the update-device command.
DeviceAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device whose status is being updated.
Status	Integer	0x00 – 0x07	Indicates the updated status of the device given by the DeviceAddress parameter: 0x00 = Standard device secured rejoin 0x01 = Standard device unsecured join 0x02 = Device left 0x03 = Standard device trust center rejoin 0x04 = High security device secured rejoin 0x05 = High security device unsecured join 0x06 = Reserved 0x07 = High security device trust center rejoin
DeviceShortAddress	Network Address	0x0000-0xffff	The 16-bit network address of the device whose status is being updated.

4.4.4.2.2 When Generated

The APSME shall generate this primitive when it receives an update-device command frame that is successfully decrypted and authenticated, as specified in sub-clause 4.4.1.2.

4.4.4.2.3 Effect on Receipt

Upon receipt of the APSME-UPDATE-DEVICE.indication primitive, the ZDO will be informed that the device referenced by the DeviceAddress parameter has undergone a status update according to the Status parameter.

4.4.5 Remove Device Services

The APSME provides services that allow a device (for example, a Trust Center) to inform another device (for example, a router) that one of its children should be removed from the network.

4.4.5.1 APSME-REMOVE-DEVICE.request

The ZDO of a device (for example, a Trust Center) shall issue this primitive when it wants to request that a parent device (for example, a router) remove one of its children from the network. For example, a Trust Center can use this primitive to remove a child device that fails to authenticate properly.

4.4.5.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-REMOVE-DEVICE.request	{
	ParentAddress,
	ChildAddress
	}

Table 4.24 specifies the parameters for the APSME-REMOVE-DEVICE.request primitive.

Table 4.24 APSME-REMOVE-DEVICE.request Parameters

Parameter Name	Type	Valid Range	Description
ParentAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that is the parent of the child device that is requested to be removed, or the router device that is requested to be removed. ^a
TargetAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the target device that is requested to be removed. If a router device is requested to be removed, then the <i>ParentAddress</i> shall be the same as the <i>TargetAddress</i> . ^b

a. CCB 1280

b. CCB 1280

4.4.5.1.2 When Generated

The ZDO (for example, on a Trust Center) shall initiate the APSME-REMOVE-DEVICE.request primitive when it wants to request that a parent device (specified

by the ParentAddress parameter) remove one of its child devices (as specified by the TargetAddress parameter), or if it wants to remove a router from the network.

If the device being removed is a router then the ParentAddress field shall be set to the EUI64 of that router and the TargetAddress shall be set to the same value.⁴⁰

4.4.5.1.3 Effect on Receipt

Upon receipt of the APSME-REMOVE-DEVICE.request primitive the device shall first create a remove-device command frame (see sub-clause 4.4.9.3). The child address field of this command frame shall be set to the ChildAddress parameter. This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified by the ParentAddress parameter by issuing a NLDE-DATA.request primitive.

4.4.5.2 APSME-REMOVE-DEVICE.indication

The APSME shall issue this primitive to inform the ZDO that it received a remove-device command frame.

4.4.5.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-REMOVE-DEVICE.indication	{
	SrcAddress,
	ChildAddress
	}

Table 4.25 specifies the parameters for the APSME-REMOVE-DEVICE.indication primitive.

Table 4.25 APSME-REMOVE-DEVICE.indication Parameters

Parameter Name	Type	Valid Range	Description
SrcAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device requesting that a child device be removed.
ChildAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the child device that is requested to be removed.

40. CCB 1280

4.4.5.2.2 When Generated

The APSME shall generate this primitive when it receives a remove-device command frame that is successfully decrypted and authenticated, as specified in sub-clause 4.4.1.2.

4.4.5.2.3 Effect on Receipt

Upon receipt of the APSME-REMOVE-DEVICE.indication primitive the ZDO shall be informed that the device referenced by the SrcAddress parameter is requesting that the child device referenced by the ChildAddress parameter be removed from the network.

4.4.6 Request Key Services

The APSME provides services that allow a device to request the active network key or a master key from another device (for example, its Trust Center).

4.4.6.1 APSME-REQUEST-KEY.request

This primitive allows the ZDO to request either the active network key or a new end-to-end application key (master or link).

4.4.6.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-REQUEST-KEY.request	{
	DestAddress,
	KeyType,
	PartnerAddress
	}

Table 4.26 specifies the parameters for the APSME-REQUEST-KEY.request primitive.

Table 4.26 APSME-REQUEST-KEY.request Parameters

Parameter Name	Type	Valid Range	Description
DestAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device to which the request-key command should be sent.
KeyType	Octet	0x00-0xFF	The type of key being requested: 0x01 = Network key 0x02 = Application key 0x04 = Trust Center Link Key 0x00 and 0x03-0xFF = Reserved
PartnerAddress	Device Address	Any valid 64-bit address	If the KeyType parameter indicates an application key, this parameter shall indicate an extended 64-bit address of a device that shall receive the same key as the device requesting the key.

4.4.6.1.2 When Generated

The ZDO of a device shall generate the APSME-REQUEST-KEY.request primitive when it requires either the active network key or a new end-to-end application key (master or link). An application link key with the Trust Center is also known as a Trust Center Link Key.

4.4.6.1.3 Effect on Receipt

Upon receipt of the APSME-REQUEST-KEY.request primitive, the device shall first create a request-key command frame (see sub-clause 4.4.9.5). The key type field of this command frame shall be set to the same value as the KeyType parameter. If the KeyType parameter is 0x02 (that is, an application key), then the partner address field of this command frame shall be the PartnerAddress parameter. Otherwise, the partner address field of this command frame shall not be present.

This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified by the DestAddress parameter by issuing a NLDE-DATA.request primitive.

4.4.6.2 APSME-REQUEST-KEY.indication

The APSME shall issue this primitive to inform the ZDO that it received a request-key command frame.

4.4.6.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-REQUEST-KEY.indication	{
	SrcAddress,
	KeyType,
	PartnerAddress
	}

Table 4.27 specifies the parameters for the APSME-REQUEST-KEY.indication primitive.

Table 4.27 APSME-REQUEST-KEY.indication Parameters

Parameter Name	Type	Valid Range	Description
SrcAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that sent the request-key command.
KeyType	Octet	0x00-0xFF	The type of key being requested: 0x01 = Network key 0x02 = Application key 0x04 = Trust Center Link Key 0x00 and 0x03-0xFF = Reserved
PartnerAddress	Device Address	Any valid 64-bit address	If the KeyType parameter indicates an application key, this parameter shall indicate an extended 64-bit address of a device that shall receive the same key as the device requesting the key.

4.4.6.2.2 When Generated

The APSME shall generate this primitive when it receives a request-key command frame that is successfully decrypted and authenticated, as specified in sub-clause 4.4.1.2.

4.4.6.2.3 Effect on Receipt

Upon receipt of the APSME-REQUEST-KEY.indication primitive, the ZDO shall be informed that the device referenced by the SrcAddress parameter is requesting a key. The type of key being requested shall be indicated by the KeyType parameter and if the KeyType parameter is 0x02 (that is, an application key), the PartnerAddress parameter shall indicate a partner device which shall receive the same key as the device requesting the key (that is, the device indicated by the SrcAddress parameter).

4.4.7 Switch Key Services

The APSME provides services that allow a device (for example, the Trust Center) to inform another device that it should switch to a new active network key.

4.4.7.1 APSME-SWITCH-KEY.request

This primitive allows a device (for example, the Trust Center) to request that another device switch to a new active network key.

4.4.7.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-SWITCH-KEY.request	{
	DestAddress,
	KeySeqNumber
	}

Table 4.28 specifies the parameters for the APSME-SWITCH-KEY.request primitive.

Table 4.28 APSME-SWITCH-KEY.request Parameters

Parameter Name	Type	Valid Range	Description
DestAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device to which the switch-key command is sent.
KeySeqNumber	Octet	0x00-0xFF	A sequence number assigned to a network key by the Trust Center and used to distinguish network keys.

4.4.7.1.2 When Generated

The ZDO of a device (for example, the Trust Center) shall generate the APSME-SWITCH-KEY.request primitive when it wants to inform a device to switch to a new active network key.

4.4.7.1.3 Effect on Receipt

Upon receipt of the APSME-SWITCH-KEY.request primitive, the device shall first create a switch-key command frame (see sub-clause 4.4.9.6). The sequence number field of this command frame shall be set to the same value as the KeySeqNumber parameter.

This command frame shall be security-protected as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, sent to the device specified by the DestAddress parameter by issuing a NLDE-DATA.request primitive.

4.4.7.2 APSME-SWITCH-KEY.indication

The APSME shall issue this primitive to inform the ZDO that it received a switch-key command frame.

4.4.7.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-SWITCH-KEY.indication	{
	SrcAddress,
	KeySeqNumber
	}

Table 4.29 specifies the parameters for the APSME-SWITCH-KEY.indication primitive.

Table 4.29 APSME-SWITCH-KEY.indication Parameters

Parameter Name	Type	Valid Range	Description
SrcAddress	Device Address	Any valid 64-bit address	The extended 64-bit address of the device that sent the switch-key command.
KeySeqNumber	Octet	0x00-0xFF	A sequence number assigned to a network key by the Trust Center and used to distinguish network keys.

4.4.7.2.2 When Generated

The APSME shall generate this primitive when it receives a switch-key command frame that is successfully decrypted and authenticated, as specified in sub-clause 4.4.1.2.

4.4.7.2.3 Effect on Receipt

Upon receipt of the APSME-SWITCH-KEY.indication primitive the ZDO shall be informed that the device referenced by the SrcAddress parameter is requesting that the network key referenced by the KeySeqNumber parameter become the new active network key.

4.4.7.3 Secured APDU Frame

The APS layer frame format consists of APS header and APS payload fields (see Figure 2.4.) The APS header consists of frame control and addressing fields. When security is applied to an APDU frame, the security bit in the APS frame control field shall be set to 1 to indicate the presence of the auxiliary frame header. The format for the auxiliary frame header is given in sub-clause 4.5.1. The format

of a secured APS layer frame is shown in Figure 4.5. The auxiliary frame header is situated between the APS header and payload fields.

Octets: Variable	5 or 6	Variable	
Original APS header ([B7], clause 7.1)	Auxiliary frame header	Encrypted payload	Encrypted message integrity code (MIC)
		Secure frame payload = output of CCM*	
Full APS header		Secured APS payload	

Figure 4.5 Secured APS Layer Frame Format

4.4.8 Entity Authentication Services

The APSME provides services that allow two devices to mutually authenticate each other. The process authenticates the originator of the data by using a random challenge with a response based on a pre-shared secret, in this case, a key. It also allows optional authenticated data transfer.

4.4.8.1 APSME-AUTHENTICATE.request

The APSME-AUTHENTICATE.request primitive is used for initiating entity authentication or responding to an entity authentication initiated by another device. This primitive can be used when there is a need to authenticate another device without using frame security. The protocol confirms authenticity based on the two devices sharing a pre-shared key.

4.4.8.1.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-AUTHENTICATE.request	{ PartnerAddress, Action, RandomChallenge }
----------------------------	---

Table 4.30 specifies the parameters for the APSME-AUTHENTICATE.request primitive.

Table 4.30 APSME-AUTHENTICATE.request Parameter

Parameter Name	Type	Valid Range	Description
PartnerAddress	DevAddress	Any valid 64-bit address	The extended, 64-bit IEEE address of the counterpart device in the entity authentication request.
Action	Enumeration	INITIATE, RESPOND_ACCEPT, RESPOND_REJECT	Indicates the action required. See Table 4.31.
RandomChallenge	Set of 16 octets	-	The 16-octet random challenge originally received from the initiator. This parameter is only valid if the Action parameter is equal to RESPOND_ACCEPT.

Table 4.31 Action Parameter Enumeration

Enumeration	Value	Description
INITIATE	0x00	Initiate the entity authentication.
RESPOND_ACCEPT	0x01	Respond to the entity authentication request, accepting it.
RESPOND_REJECT	0x02	Respond to the entity authentication request, rejecting it.

4.4.8.1.2 When Generated

The ZDO on an initiator or responder device will generate this primitive when it needs to initiate or respond to entity authentication. If the ZDO is responding to an APSME-AUTHENTICATE.indication primitive, it will set the RandomChallenge parameter to the corresponding RandomChallenge parameter in the indication.

4.4.8.1.3 Effect on Receipt

The receipt of an APSME-AUTHENTICATE.request primitive with the Action parameter set to INITIATE shall cause the APSME to initiate the mutual entity authentication protocol, described in clause 4.4.8.5. The local APSME shall act as the initiator of this protocol and the APSME indicated by the PartnerAddress parameter shall act as the responder of this protocol.

The receipt of an APSME-AUTHENTICATE.request primitive with the Action parameter set to RESPOND_ACCEPT shall cause the APSME to participate in the response of the mutual entity authentication protocol, described in

clause 4.4.8.5. The local APSME shall act as the responder of this protocol and the APSME indicated by the PartnerAddress parameter shall act as the initiator of this protocol. If the Action parameter is set to RESPOND_REJECT, the entity authentication will not take place.

4.4.8.2 APSME-AUTHENTICATE.confirm

This primitive shall be issued to the ZDO of the initiator and responder devices upon completion or failure of entity authentication.

4.4.8.2.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-AUTHENTICATE.confirm	{
	Address,
	Status
	}

Table 4.32 specifies the parameters of the APSME-AUTHENTICATE.confirm primitive. In addition to these codes, if an NLDE-DATA.confirm primitive with a Status parameter set to a value other than SUCCESS is issued when sending one of the protocol messages, the Status parameter of the APSME-AUTHENTICATE.confirm primitive shall be set to that received from the NWK layer.

Table 4.32 APSME-AUTHENTICATE.confirm Parameters

Parameter Name	Type	Valid Range	Description
Address	DevAddress	Any valid 64-bit address.	The extended, 64-bit IEEE address of the device with which the entity authentication took place.
Status	Enumeration	Value given by Table 4.31 or any status value returned from the NLDE-DATA.confirm primitive.	The final status of the entity authentication.

4.4.8.2.2 When Generated

The APSME of the initiator or responder shall issue this primitive to its ZDO upon completion of entity authentication.

4.4.8.2.3 Effect on Receipt

Upon receiving the APSME-AUTHENTICATE.confirm primitive, the ZDO of the initiator is notified of the result of its request to authenticate the responder. If the transfer was successful, the Status parameter will be set to SUCCESS and the ZDO will learn that it shares a key with the responder and that it has received authenticated data from the responder. Otherwise, the Status parameter will indicate the error.

The ZDO of the responder is notified of the result of the transfer of authenticated data from the initiator. If the transfer was successful, the Status parameter will be set to SUCCESS and the ZDO will learn that it shares a key with the initiator and that it has received authenticated data from the initiator. Otherwise, the Status parameter will indicate the error.

4.4.8.3 APSME-AUTHENTICATE.indication

The APSME in the responder issues this primitive to its ZDO when it receives an initial authentication message from an initiator.

4.4.8.3.1 Semantics of the Service Primitive

This primitive shall provide the following interface:

APSME-AUTHENTICATE.indication	{
	InitiatorAddress,
	RandomChallenge,
	}

Table 4.33 specifies the parameters of the APSME-AUTHENTICATE.indication primitive.

Table 4.33 APSME-AUTHENTICATE.indication Parameters

Parameter Name	Type	Valid Range	Description
InitiatorAddress	DevAddress Enumeration	Any valid 64-bit address	The extended, 64-bit IEEE address of the initiator device.
RandomChallenge	Set of 16 octets	-	The 16-octet random challenge received from the initiator.

4.4.8.3.2 When Generated

The APSME in the responder device shall issue this primitive to the ZDO when a request to start an entity authentication is received from an initiator.

4.4.8.3 Effect on Receipt

Upon receiving the APSME-AUTHENTICATE.indication primitive, the ZDO will determine whether it wishes to participate in entity authentication with the initiator specified by the InitiatorAddress parameter. If it does, the ZDO will respond using the APSME-AUTHENTICATE.request primitive, setting the Action parameter to RESPOND_ACCEPT and the corresponding RandomChallenge parameter in the APSME-AUTHENTICATE.request primitive to the RandomChallenge parameter. If it does not wish to participate in entity authentication with the initiator, the ZDO will respond using the APSME-AUTHENTICATE.request primitive, setting the Action parameter to RESPOND_REJECT.

4.4.8.4 Data Service Message Sequence Chart

Figure 4.6 illustrates the sequence of primitives necessary for a successful entity authentication between two devices.

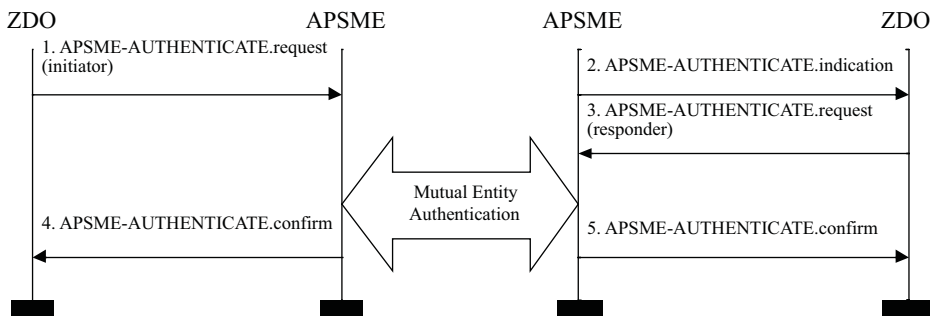


Figure 4.6 Sequence Chart for Successful APSME-AUTHENTICATE Primitives

4.4.8.5 The Mutual Entity Authentication Protocol

The APSME on the initiator and responder execute the mutual entity authentication scheme specified in sub-clause B.8. The messages sent during the scheme specified in sub-clause B.8 shall be assigned to the frame names given in Table 4.34. The formats for these entity authentication frames are given in sub-clause 4.4.9.7.

The KeyType sub-field in the initiator and responder challenge frames shall be set to 0x00 to indicate that the shared key is the active network key shared between the initiator and the responder.

The MacKey as specified in prerequisite step 2 of sub-clauses B.8.1 and B.8.2 shall be the active network key shared between the initiator and the responder obtained using NLME-GET.request on the *nwkSecurityMaterialSet*, using the key

corresponding to *nwkActiveKeySeqNumber*. If the KeySeqNumber sub-field of the incoming initiator or responder challenge frame does not match *nwkActiveKeySeqNumber* or the network key is not available, the local APSME shall issue the APSME-AUTHENTICATE.confirm primitive with the Status parameter set to NO_KEY.

Text1 as specified in sub-clause B.8.2 input 2 and sub-clause B.8.2 step 7 shall be set to the outgoing frame counter associated with the active network key of the responder using the octet representation specified in sub-clause A.1. Using NLME-GET.request, this is the OutgoingFrameCounter entry of the *nwkSecurityMaterialSet* entry which has its KeySeqNumber entry equal to *nwkActiveKeySeqNumber*. If the frame counter is not available, the responder APSME shall issue the APSME-AUTHENTICATE.confirm primitive with the Status parameter set to NO_DATA. The incoming frame counter corresponding to the responder, associated with the active network key of the initiator shall be set to *Text1* as specified in sub-clause B.8.1 step 6. Using NLME-SET.request, this is the IncomingFrameCounter entry of the IncomingFrameCounterSet entry, where the SenderAddress entry corresponds to the responder, of the *nwkSecurityMaterialSet* entry which has its KeySeqNumber entry equal to *nwkActiveKeySeqNumber*.

Text2 as specified in sub-clause B.8.1 input 1 and sub-clause B.8.1 step 4 shall be set to the outgoing frame counter associated with the active network key of the initiator using the octet representation specified in sub-clause A.1. Using NLME-GET.request, this is the OutgoingFrameCounter entry of the *nwkSecurityMaterialSet* entry which has its KeySeqNumber entry equal to *nwkActiveKeySeqNumber*. If the frame counter is not available, the responder APSME shall issue the APSME-AUTHENTICATE.confirm primitive with the Status parameter set to NO_DATA. The incoming frame counter corresponding to the initiator associated with the active network key of the responder shall be set to *Text2* as specified in sub-clause B.8.2 step 3. Using NLME-SET.request, this is the IncomingFrameCounter entry of the IncomingFrameCounterSet entry, where the SenderAddress entry corresponds to the initiator, of the *nwkSecurityMaterialSet* entry which has its KeySeqNumber entry equal to *nwkActiveKeySeqNumber*.

When the NLDE-DATA.request primitive is issued to send either the challenge frame or the MAC and data frame, the SecurityEnable parameter shall always be set to FALSE to indicate that no security is used at the network layer.

The authentication scheme shall be guarded by the initiator starting a timer of period *apsSecurityTimeoutPeriod* from when the challenge frame is sent until the responder MAC and data frame is received back. Similarly, the responder starts a timer of period *apsSecurityTimeoutPeriod* when it sends a responder challenge frame and must receive the corresponding initiator MAC and data frame with that period.

During the authentication scheme, if any error condition listed in Table 4.35 is detected then the scheme shall be aborted and the local APSME shall issue the APSME-AUTHENTICATE.confirm primitive with the Status parameter set as indicated in Table 4.35. If no error conditions occur (*i.e.*, the authentication scheme outputs “valid”), then the initiator shall consider that secure communications with the responder using the indicated key are possible. The initiator and responder shall issue the APSME-AUTHENTICATE.confirm primitive with the Status parameter set to SUCCESS.

Table 4.34 Mapping of Frame Names to Mutual Entity Authentication Scheme Messages

Frame Name	Description	Reference
APS_CMD_EA_INIT_CHLNG	Sent by initiator during action step 1 (sub-clause B.8.1).	4.4.9.7.1
APS_CMD_EA_RSP_CHLNG	Sent by responder during action step 2 (sub-clause B.8.2).	4.4.9.7.2
APS_CMD_EA_INIT_MAC_DATA	Sent by initiator during action step 5 (sub-clause B.8.1).	4.4.9.7.3
APS_CMD_EA_RSP_MAC_DATA	Sent by responder during action step 8 (sub-clause B.8.2).	4.4.9.7.4

Table 4.35 Mapping of Mutual Entity Authentication Error Conditions to Status Codes

Status Description	Status Code	Value
No errors occur.	SUCCESS	0x00
An invalid parameter was input to one of the key establishment primitives.	INVALID_PARAMETER	0x01
No authentication key exists.	NO_KEY	0x02
No authentication data exists.	NO_DATA	0x03
Challenge is invalid: Initiator during action step 2 (sub-clause B.8.1). Responder during action step 1 (sub-clause B.8.2).	INVALID_CHALLENGE	0x04

Table 4.35 Mapping of Mutual Entity Authentication Error Conditions to Status Codes

Status Description	Status Code	Value
MAC transformation outputs invalid: Initiator during action step 4 (sub-clause B.8.1). Responder during action steps 4 and 7 (sub-clause B.8.2).	INVALID_MAC	0x05
Tag checking transformation outputs invalid: Initiator during action step 3 (sub-clause B.8.1). Responder during action step 6 (sub-clause B.8.2).	INVALID_KEY	0x06
The initiator or responder waits for an expected incoming message for time greater than <i>apsSecurityTimeoutPeriod</i> .	TIMEOUT	0x07

4.4.9 Command Frames

The APS layer command frame formats are given in this clause.

All APS layer command frames are sent secured unless explicitly specified.

Command identifier values are shown in Table 4.36.

Table 4.36 Command Identifier Values

Command Identifier	Value
APS_CMD_SKKE_1	0x01
APS_CMD_SKKE_2	0x02
APS_CMD_SKKE_3	0x03
APS_CMD_SKKE_4	0x04
APS_CMD_TRANSPORT_KEY	0x05
APS_CMD_UPDATE_DEVICE	0x06
APS_CMD_REMOVE_DEVICE	0x07
APS_CMD_REQUEST_KEY	0x08
APS_CMD_SWITCH_KEY	0x09
APS_CMD_EA_INIT_CHLNG	0x0A
APS_CMD_EA_RSP_CHLNG	0x0B
APS_CMD_EA_INIT_MAC_DATA	0x0C
APS_CMD_EA_RSP_MAC_DATA	0x0D
APS_CMD_TUNNEL	0x0E

4.4.9.1 Key-Establishment Commands

The APS command frames used during key establishment are specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present. All key establishment command frames are sent unsecured.

The generic SKKE command frame shall be formatted as illustrated in Figure 4.7.

Octets: 1	1	1	8	8	16
Frame control	APS counter	APS command identifier	Initiator address	Responder address	Data
APS header		Payload			

Figure 4.7 Generic SKKE Frame Command Format

4.4.9.1.1 Command Identifier Field

The command identifier field shall indicate the APS command type. For SKKE frames, the command identifier shall indicate either an SKKE-1, SKKE-2, SKKE-3, or SKKE-4 frame, depending on the frame type (APS_CMD_SKKE_1, APS_CMD_SKKE_2, APS_CMD_SKKE_3, APS_CMD_SKKE_4, see Table 4.36).

4.4.9.1.2 Initiator Address Field

The initiator address field shall be the 64-bit extended address of the device that acts as the initiator in the key-establishment protocol.

4.4.9.1.3 Responder Address Field

The responder address field shall be the 64-bit extended address of the device that acts as the responder in the key-establishment protocol.

4.4.9.1.4 Data Field

The content of the data field depends on the command identifier field (that is, SKKE-1, SKKE-2, SKKE-3, or SKKE-4). Clauses 4.4.9.1.4.1 through 4.4.9.1.4.4 describe the content of the data field for each command type.

4.4.9.1.4.1 SKKE-1 Frame

The data field shall be the octet representation of the challenge *QEU* generated by the initiator during action step 1 of sub-clause B.7.1.

4.4.9.1.4.2 SKKE-2 Frame

The data field shall be the octet representation of the challenge *QEV* generated by the responder during action step 2 of sub-clause B.7.2.

4.4.9.1.4.3 SKKE-3 Frame

The data field shall be the octet representation of the string *MacTag*₂ generated by the initiator during action step 1 of sub-clause B.7.1.

4.4.9.1.4.4 SKKE-4 Frame

The data field shall be the octet representation of the string *MacTag*₁ generated by the responder during action step 10 of sub-clause B.7.2.

4.4.9.2 Transport-Key Commands

The transport-key command frame shall be formatted as illustrated in Figure 4.8. The optional fields of the APS header portion of the general APS frame format shall not be present.

Octets: 1	1	1	1	Variable
Frame control	APS counter	APS command identifier	Key type	Key descriptor
APS header		Payload		

Figure 4.8 Transport-Key Command Frame

4.4.9.2.1 Command Identifier Field

The command identifier field shall indicate the transport-key APS command type (APS_CMD_TRANSPORT_KEY, see Table 4.36).

4.4.9.2.2 Key Type Field

This field is 8 -bits in length and describes the type of key being transported. The different types of keys are enumerated in Table 4.14.

4.4.9.2.3 Key Descriptor Field

This field is variable in length and shall contain the actual (unprotected) value of the transported key along with any relevant identification and usage parameters. The information in this field depends on the type of key being transported (as indicated by the key type field — see sub-clause 4.4.9.2.2) and shall be set to one of the formats described in the following subsections.

4.4.9.2.3.1 Trust Center Master or Link Key Descriptor Field

If the key type field is set to 0 or 4, the key descriptor field shall be formatted as shown in Figure 4.9.

Octets: 16	8	8
Key	Destination address	Source address

Figure 4.9 Trust Center Master Key Descriptor Field in Transport-Key Command

- The key sub-field shall contain the master key that should be used to set up link keys with the Trust Center.
- The destination address sub-field shall contain the address of the device which should use this master key.
- The source address sub-field shall contain the address of the device (for example, the Trust Center) which originally sent this master key.

4.4.9.2.3.2 Network Key Descriptor Field

If the key type field is set to 1, 5 or 6, this field shall be formatted as shown in Figure 4.10.

Octets: 16	1	8	8
Key	Sequence number	Destination address	Source address

Figure 4.10 Network Key Descriptor Field in Transport-Key Command

- The key sub-field shall contain a network key.
- The sequence number sub-field shall contain the sequence number associated with this network key.
- The destination address sub-field shall contain the address of the device which should use this network key.
- If the network key is sent to a broadcast address, the destination address sub-field shall be set to the all-zero string and shall be ignored upon reception.
- The source address field sub-shall contain the address of the device (for example, the Trust Center) which originally sent this network key.

4.4.9.2.3.3 Application Master and Link Key Descriptor Field

If the key type field is set to 2 or 3, this field shall be formatted as shown in Figure 4.13.

Octets: 16	8	1
Key	Partner address	Initiator flag

Figure 4.11 Application Master Key Descriptor in Transport-Key Command

- The key sub-field shall contain a master or link key that is shared with the device identified in the partner address sub-field.
- The partner address sub-field shall contain the address of the other device that was sent this link or master key.
- The initiator flag sub-field shall be set to 1 if the device receiving this packet requested this key. Otherwise, this sub-field shall be set to 0.

4.4.9.3 Update Device Commands

The APS command frame used for device updates is specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present.

The update-device command frame shall be formatted as illustrated in Figure 4.12.

Octets: 1	1	1	8	2	1
Frame control	APS counter	APS command identifier	Device Address	Device short address	Status
APS Header			Payload		

Figure 4.12 Update-Device Command Frame Format

4.4.9.3.1 Command Identifier Field

The command identifier field shall indicate the update-device APS command type (APS_CMD_UPDATE_DEVICE, see Tables 4.36).

4.4.9.3.2 Device Address Field

The device address field shall be the 64-bit extended address of the device whose status is being updated.

4.4.9.3.3 Device Short Address Field

The device short address field shall be the 16-bit network address of the device whose status is being updated.

4.4.9.3.4 Status Field

The status field shall be assigned a value as described for the Status parameter in Table 4.22.

4.4.9.4 Remove Device Commands

The APS command frame used for removing a device is specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present.

The remove-device command frame shall be formatted as illustrated in Figure 4.13.

Octets: 1	1	1	8
Frame control	APS counter	APS command identifier	Target address ^a
APS Header		Payload	

a. CCB 1280

Figure 4.13 Remove-Device Command Frame Format

4.4.9.4.1 Command Identifier Field

The command identifier field shall indicate the remove-device APS command type (APS_CMD_REMOVE_DEVICE, see Table 4.36).

4.4.9.4.2 Target Address Field

The target address field shall be the 64-bit extended address of the device that is requested to be removed from the network.⁴¹

4.4.9.5 Request-Key Commands

The APS command frame used by a device for requesting a key is specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present.

41. CCB 1280

The request-key command frame shall be formatted as illustrated in Figure 4.14.

Octets: 1	1	1	1	0/8
Frame control	APS counter	APS command identifier	Key type	Partner address
APS Header		Payload		

Figure 4.14 Request-Key Command Frame Format

4.4.9.5.1 Command Identifier Field

The command identifier field shall indicate the request-key APS command type (APS_CMD_REQUEST_KEY, see Table 4.36).

4.4.9.5.2 Key Type Field

The key type field shall be set to 1 when the network key is being requested, shall be set to 2 when an application key is being requested.

4.4.9.5.3 Partner Address Field

When the key type field is 2 (that is, an application key), the partner address field shall contain the extended 64-bit address of the partner device that shall be sent the key. Both the partner device and the device originating the request-key command will be sent the key.

When the key-type field is 1 or 4 (that is, a network key or a trust center link key), the partner address field will not be present.

4.4.9.6 Switch-Key Commands

The APS command frame used by a device for switching a key is specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present.

The switch-key command frame shall be formatted as illustrated in Figure 4.15.

Octets: 1	1	1	1
Frame control	APS counter	APS command identifier	Sequence number
APS Header		Payload	

Figure 4.15 Switch-key Command Frame Format

4.4.9.6.1 Command Identifier Field

The command identifier field shall indicate the switch-key APS command type (APS_CMD_SWITCH_KEY, see Table 4.36).

4.4.9.6.2 Sequence Number Field

The sequence number field shall contain the sequence number identifying the network key to be made active.

4.4.9.7 Entity Authentication Frames

The APS command frames used during entity authentication are specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present. The initiator and responder should implement random delays on their respective transmissions to avoid packet transmission collisions.

4.4.9.7.1 Entity Authentication Initiator Challenge Frame

This frame is the first frame sent by the initiator to the responder during the mutual entity authentication protocol and shall be formatted as illustrated in Figure 4.16.

Octets: 1	1	1	Variable	8	8	16
Frame control	APS counter	APS command identifier	KeyInfo	Initiator	Responder	Challenge
APS Header		Payload				

Figure 4.16 Entity Authentication Initiator Challenge Frame Format

4.4.9.7.1.1 Command Identifier Field

The command identifier field shall indicate the Entity Authentication Initiator Challenge APS command type (APS_CMD_EA_INIT_CHLNG, see Table 4.36).

4.4.9.7.1.2 KeyInfo Field

The KeyInfo field is divided into two subfields as illustrated in Figure 4.17.

Octets: 1	0/1
KeyType	KeySeqNumber

Figure 4.17 KeyInfo Field Format

4.4.9.7.1.2.1 KeyType Subfield

The KeyType field is 1 octet in length and shall be set to one of the non-reserved values in Table 4.37.

Table 4.37 Values of the KeyType Sub-Field

Value	Description
0x00	Active network key.
0x01	Link key shared between initiator and responder.
0x02-0xff	Reserved.

4.4.9.7.1.2.2 KeySeqNumber Subfield

The KeySeqNumber sub-field shall be set to the key sequence number of the active network key.

4.4.9.7.1.3 Initiator Field

The initiator field shall be set to the 64-bit extended address of the device that acts as the initiator of the scheme.

4.4.9.7.1.4 Responder Field

The responder field shall be set to the 64-bit extended address of the device that acts as the responder to the scheme.

4.4.9.7.1.5 Challenge Field

The challenge field shall be the octet representation of the challenge *QEU* generated by the initiator during action step 1 of sub-clause B.8.1.

4.4.9.7.2 Entity Authentication Response Challenge Frame

This frame is the first frame sent by the responder to the initiator during the mutual entity authentication protocol and shall be formatted as illustrated in Figure 4.18.

Octets: 1	1	1	Variable	8	8	16
Frame control	APS counter	APS command identifier	KeyInfo	Initiator	Responder	Challenge
APS Header		Payload				

Figure 4.18 Entity Authentication Responder Challenge Frame Format

4.4.9.7.2.1 Command Identifier Field

The command identifier field shall indicate the Entity Authentication Responder Challenge APS command type (APS_CMD_EA_RSP_CHLNG, see Table 4.36).

4.4.9.7.2.2 KeyInfo Field

The KeyInfo field is divided into two subfields as illustrated in Figure 4.19.

Octets: 1	0/1
KeyType	KeySeqNumber

Figure 4.19 KeyInfo Field Format

4.4.9.7.2.2.1 KeyType Sub-Field

The KeyType field shall be set to 0x00 to indicate that the shared key is the active network key shared between the initiator and the responder.

4.4.9.7.2.2.2 KeySeqNumber Sub-Field

The KeySeqNumber sub-field shall be set to the key sequence number of the active network key.

4.4.9.7.2.3 Initiator Field

The initiator field shall be set to the 64-bit extended address of the device that acts as the initiator of the scheme.

4.4.9.7.2.4 Responder Field

The responder field shall be set to the 64-bit extended address of the device that acts as the responder to the scheme.

4.4.9.7.2.5 Challenge Field

The challenge field shall be the octet representation of the challenge *QEV* generated by the responder during action step 2 of sub-clause B.8.2.

4.4.9.7.3 Entity Authentication Initiator MAC and Data Frame

This is the second frame sent by initiator to the responder during the mutual entity authentication protocol, and shall be formatted as illustrated in Figure 4.20.

Octets: 1	1	1	16	1	4
Frame control	APS counter	APS command identifier	MAC	DataType	Data
APS Header		Payload			

Figure 4.20 Entity Authentication Initiator MAC and Data Frame Format

4.4.9.7.3.1 Command Identifier Field

The command identifier field shall indicate the Entity Authentication Initiator MAC and Data APS command type (APS_CMD_EA_RSP_MAC_DATA, see Table 4.36).

4.4.9.7.3.2 MAC Field

The MAC field shall be the octet representation of the string *MacTag₂* generated by the initiator during action step 4 of sub-clause B.8.1.

4.4.9.7.3.3 DataType Field

The DataType field shall be set to 0x00 to indicate the frame counter associated with the active network key.

4.4.9.7.3.4 Data Field

The Data field shall be octet representation of the string *Text₂*, i.e. the frame counter associated with the active network key.

4.4.9.7.4 Entity Authentication Responder MAC and Data Frame

This is the second frame sent by the responder to the initiator during mutual entity authentication protocol, and shall be formatted as illustrated in Figure 4.21.

Octets: 1	1	1	16	1	4
Frame control	APS counter	APS command identifier	MAC	DataType	Data
APS Header		Payload			

Figure 4.21 Entity Authentication Responder MAC and Data Frame Format

4.4.9.7.4.1 Command Identifier Field

The command identifier field shall indicate the Entity Authentication Responder MAC and Data command (APS_CMD_EA_RSP_MAC_DATA, see Table 4.36).

4.4.9.7.4.2 MAC Field

The MAC field shall be the octet representation of the string *MacTag₁* generated by the responder during action step 8 of sub-clause B.8.2

4.4.9.7.4.3 DataType Field

The DataType field shall be set to 0x00 to indicate the frame counter associated with the active network key.

4.4.9.7.4.4 Data Field

The Data field shall be octet representation of the string *Text₁*, i.e. the frame counter associated with the active network key.

4.4.9.8 Tunnel Commands

The APS command frame used by a device for sending a command to a device that lacks the current network key is specified in this clause. The optional fields of the APS header portion of the general APS frame format shall not be present. The tunnel-key command frame is sent unsecured.

The tunnel-key command frame shall be formatted as illustrated in Figure 4.22.

Octets:1	1	1	8	2	13	Variable	4
Frame control	APS counter	APS command identifier	Destination address	Tunneled APS header	Tunneled auxiliary frame	Tunneled command	Tunneled APS MIC
APS Header		Payload					

Figure 4.22 Tunnel Command Frame Format

4.4.9.8.1 Command Identifier Field

The command identifier field shall indicate the tunnel APS command type (APS_CMD_TUNNEL, see Table 4.36).

4.4.9.8.2 Destination Address

The destination address field shall be the 64-bit extended address of the device that is to receive the tunnelled command.

4.4.9.8.3 Tunnelled Auxiliary Frame Field

The tunnelled auxiliary frame field shall be the auxiliary frame (see sub-clause 4.5.1) used to encrypt the tunnelled command. The auxiliary frame shall indicate that a link key was used and shall included the extended nonce field.

4.4.9.8.4 Tunnelled Command Field

The tunnelled command field shall be the APS command frame to be sent to the destination.

4.4.10 Security-Related AIB Attributes

The AIB contains attributes that are required to manage security for the APS layer. Each of these attributes can be read or written using the APSME-GET.request and APSME-SET.request primitives, respectively. The security-related attributes contained in the APS PIB are presented in Tables 4.38 and 4.39.

Table 4.38 AIB Security Attributes

Attribute	Identifier	Type	Range	Description	Default
<i>apsDeviceKeyPairSet</i>	0xaa	Set of key-pair descriptor entries. See Table 4.39.	Variable	A set of key-pair descriptors containing master and link key pairs shared with other devices.	-
<i>apsTrustCenterAddress</i>	0xab	Device address	Any valid 64-bit address	Identifies the address of the device's Trust Center.	-
<i>apsSecurityTimeOutPeriod</i>	0xac	Integer	0x0000-0xFFFF	The period of time a device will wait for the next expected security protocol frame (in milliseconds).	Defined in stack profile ^a

a. ZigBee Document 12-0220-04

Table 4.39 Elements of the Key-Pair Descriptor

Name	Type	Range	Description	Default
DeviceAddress	Device address	Any valid 64-bit address	Identifies the address of the entity with which this key-pair is shared.	-
MasterKey	Set of 16 octets	-	The actual value of the master key.	-
LinkKey	Set of 16 octets	-	The actual value of the link key.	-
OutgoingFrame-Counter	Set of 4 octets	0x00000000-0xFFFFFFFF	Outgoing frame counter for use with this link key.	0x00000000
IncomingFrame-Counter	Set of 4 octets	0x00000000-0xFFFFFFFF	Incoming frame counter value corresponding to <i>DeviceAddress</i> .	0x00000000
apsLinkKeyType	Enumeration	0x00 – 0x01	The type of link key in use. This will determine the security policies associated with sending and receiving APS messages. 0x00 = Unique Link Key 0x01 = Global Link Key ^a	0x00

a. CCB 1313

4.5 Common Security Elements

This clause describes security-related features that are used in more than one ZigBee layer. The NWK and APS layers shall use the auxiliary header as specified in sub-clause 4.5.1 and the security parameters specified in sub-clause 4.5.2. The formatting of all frames and fields in this specification are depicted in the order in which they are transmitted by the NWK layer, from left to right, where the leftmost bit is transmitted first in time. Bits within each field are numbered from 0 (leftmost and least significant) to k-1 (rightmost and most significant), where the length of the field is k bits. Fields that are longer than a single octet are sent to the next layer in the order from the octet containing the lowest numbered bits to the octet containing the highest numbered bits.

4.5.1 Auxiliary Frame Header Format

The auxiliary frame header, as illustrated by Figure 4.23, shall include a security control field and a frame counter field, and may include a sender address field and key sequence number field.

Octets: 1	4	0/8	0/1
Security control	Frame counter	Source address	Key sequence number

Figure 4.23 Auxiliary Frame Header Format

4.5.1.1 Security Control Field

The security control field shall consist of a security level, a key identifier, and an extended nonce sub-field and shall be formatted as shown in Figure 4.24.

Bit: 0-2	3-4	5	6-7
Security level	Key identifier	Extended nonce	Reserved

Figure 4.24 Security Control Field Format

4.5.1.1.1 Security Level Sub-Field

The security level identifier indicates how an outgoing frame is to be secured, how an incoming frame purportedly has been secured; it also indicates whether or not the payload is encrypted and to what extent data authenticity over the frame is provided, as reflected by the length of the message integrity code (MIC). The bit-length of the MIC may take the values 0, 32, 64 or 128 and determines the probability that a random guess of the MIC would be correct. The security properties of the security levels are listed in Table 4.40. Note that security level identifiers are not indicative of the relative strength of the various security levels. Also note that security levels 0 and 4 should not be used for frame security.

Table 4.40 Security Levels Available to the NWK, and APS Layers

Security Level Identifier	Security Level Sub-Field (Table 4.24)	Security Attributes	Data Encryption	Frame Integrity (length M of MIC, in Number of Octets)
0x00	'000'	None	OFF	NO (M = 0)
0x01	'001'	MIC-32	OFF	YES (M=4)
0x02	'010'	MIC-64	OFF	YES (M=8)
0x03	'011'	MIC-128	OFF	YES (M=16)

Table 4.40 Security Levels Available to the NWK, and APS Layers (Continued)

Security Level Identifier	Security Level Sub-Field (Table 4.24)	Security Attributes	Data Encryption	Frame Integrity (length M of MIC, in Number of Octets)
0x04	‘100’	ENC	ON	NO (M = 0)
0x05	‘101’	ENC-MIC-32	ON	YES (M=4)
0x06	‘110’	ENC-MIC-64	ON	YES (M=8)
0x07	‘111’	ENC-MIC-128	ON	YES (M=16)

4.5.1.1.2 Key Identifier Sub-Field

The key identifier sub-field consists of two bits that are used to identify the key used to protect the frame. The encoding for the key identifier sub-field shall be as listed in Table 4.41.

Table 4.41 Encoding for the Key Identifier Sub-Field

Key Identifier	Key Identifier Sub-Field (Table 4.24)	Description
0x00	‘00’	A data key.
0x01	‘01’	A network key.
0x02	‘10’	A key-transport key.
0x03	‘11’	A key-load key.

4.5.1.1.3 Extended Nonce Sub-Field

The extended nonce sub-field shall be set to 1 if the sender address field of the auxiliary header is present. Otherwise, it shall be set to 0.

4.5.1.2 Counter Field

The counter field is used to provide frame freshness and to prevent processing of duplicate frames.

4.5.1.3 Source Address Field

The source address field shall only be present when the extended nonce sub-field of the security control field is 1. When present, the source address field shall indicate the extended 64-bit address of the device responsible for securing the frame.

4.5.1.4 Key Sequence Number Field

The key sequence number field shall only be present when the key identifier sub-field of the security control field is 1 (that is, a network key). When present, the key sequence number field shall indicate the key sequence number of the network key used to secure the frame.

4.5.2 Security Parameters

This sub-clause specifies the parameters used for the CCM* security operations.

4.5.2.1 CCM* Mode of Operation and Parameters

Applying security to a NWK or APS frame on a particular security level corresponds to a particular instantiation of the AES-CCM* mode of operation as specified in sub-clause B.1.2. The AES-CCM* mode of operation is an extension of the AES-CCM mode that is used in the 802.15.4-2003 MAC specification and provides capabilities for authentication, encryption, or both.

The nonce shall be formatted as specified in sub-clause 4.5.2.2.

Table 4.40 gives the relationship between the security level sub-field of the security control field (Table 4.24), the security level identifier, and the CCM* encryption/authentication properties used for these operations.

4.5.2.2 CCM* Nonce

The nonce input used for the CCM* encryption and authentication transformation and for the CCM* decryption and authentication checking transformation consists of data explicitly included in the frame and data that both devices can independently obtain. Figure 4.25 specifies the order and length of the subfields of the CCM* nonce. The nonce's security control and frame counter fields shall be the same as the auxiliary header's security control and frame counter fields (as defined in sub-clause 4.5.1) of the frame being processed. The nonce's source address field shall be set to the extended 64-bit IEEE address of the device originating security protection of the frame. When the extended nonce sub-field of the auxiliary header's security control field is 1, the extended 64-bit IEEE address of the device originating security protection of the frame shall correspond to the auxiliary header's source address field (as defined in sub-clause 4.5.1) of the frame being processed

Octets: 8	4	1
Source address	Frame counter	Security control

Figure 4.25 CCM* Nonce

4.5.3 Cryptographic Key Hierarchy

The link key established between two (or more) devices via one of the key-establishment schemes specified in sub-clause 4.4.2 (or transport-key commands specified in sub-clause 4.4.3) is used to determine related secret keys, including data keys, key-transport keys, and key-load keys. These keys are determined as follows:

- 1 *Key-Transport Key*. This key is the outcome of executing the specialized keyed hash function specified in sub-clause B.1.4 under the link key with the 1-octet string '0x00' as the input string.
- 2 *Key-Load Key*. This key is the outcome of executing the specialized keyed hash function specified in sub-clause B.1.4 under the link key with as input string the 1-octet string '0x02' as the input string.
- 3 *Data Key*. This key is equal to the link key.

All keys derived from the link key shall share the associated frame counters. Also, all layers of ZigBee shall share the active network key and associated outgoing and incoming frame counters.

4.5.4 Implementation Guidelines (Informative)

This clause provides general guidelines that should be followed to ensure a secure implementation.

4.5.4.1 Random Number Generator

A ZigBee device implementing the key-establishment security service, (see sub-clause 4.2.3.1) may need a strong method of random number generation. For example, when link keys are pre-installed (e.g., in the factory), a random number may not be needed.

In all cases that require random numbers, it is critical that the random numbers are not predictable or have enough entropy, so an attacker will not be able determine them by exhaustive search. The general recommendation is that the random number generation shall meet the random number tests specified in FIPS140-2 [B13]. Methods for generation of random numbers include:

- 1 Base the random number on random clocks and counters within the ZigBee hardware;
- 2 Base the random number on random external events;
- 3 Seed each ZigBee device with a good random number from an external source during production. This random number can then used as a seed to generate additional random numbers.

A combination of these methods can be used. Since the random number generation is likely integrated into the ZigBee IC, its design — and hence the ultimate viability of any encryption/security scheme — is left up to the IC manufacturers.

4.5.4.2 Security Implementation

To avoid “bugs” that an attacker can use to his advantage, it is crucial that security be well implemented and tested. It is also desirable that the security implementation does not require re-certification for every application. Security services should be implemented and tested by security experts and should not be re-implemented or modified for different applications.

4.5.4.3 Conformance

Conformance shall be defined by the profile inheriting given in this specification. Correct implementation of selected cryptographic protocols should be verified as part of the ZigBee certification process. This verification shall include known value tests: an implementation must show that, given particular parameters, it will correctly compute the corresponding results.

4.6 Functional Description

This sub-clause provides detailed descriptions of how the security services shall be used in a ZigBee network. A description of the ZigBee coordinator’s security initialization responsibilities is given in sub-clause 4.6.1. A brief description of the Trust Center application is given in sub-clause 4.6.2. Detailed security procedures are given in sub-clause 4.6.3.

4.6.1 ZigBee Coordinator

The ZigBee coordinator shall configure the security level of the network by setting the *nwkSecurityLevel* attribute in the NIB. If the *nwkSecurityLevel* attribute is set to zero, the network will be unsecured, otherwise it will be secured.

The ZigBee coordinator shall configure the address of the Trust Center by setting the AIB attribute *apsTrustCenterAddress*. The default value of this address is the ZigBee coordinator’s own address, otherwise, the ZigBee coordinator may designate an alternate Trust Center.

4.6.2 Trust Center Application

The Trust Center application runs on a device trusted by devices within a ZigBee network to distribute keys for the purpose of network and end-to-end application

configuration management. The Trust Center shall be configured to operate in either standard or high security mode and may be used to help establish end-to-end application keys either by sending out link keys directly (that is, key-escrow capability) or by sending out master keys. These keys shall be generated at random.

4.6.2.1 High Security Mode

The high security mode of the Trust Center is designed for high security commercial applications. In this mode, the Trust Center shall maintain a list of devices, master keys, link keys and network keys that it needs to control and enforce the policies of network key updates and network admittance. In this mode, the memory required for the Trust Center grows with the number of devices in the network and the *nwkAllFresh* attribute in the NIB shall be set to TRUE. It also mandates the implementation of key establishment using SKKE and entity authentication.

4.6.2.2 Standard Security Mode

The standard security mode of the Trust Center is designed for lower-security residential applications. In this mode, the Trust Center may maintain a list of devices, master keys, link keys and network keys with all the devices in the network; however, it shall maintain a standard network key and controls policies of network admittance. In this mode, the *nwkAllFresh* attribute in the NIB shall be set to FALSE.

Each device that joins the network securely shall either have a global link key or a unique link key depending upon the application in use. It is required that the trust center have prior knowledge of the value of the link key and the type (global or unique) in order to securely join the device to the network. A global link key has the advantage that the memory required by the Trust Center does not grow with the number of devices in the network. A unique link key has the advantage of being unique for each device on the network and application communications can be secured from other devices on the network. Both types of keys may be used on the network, but a device shall only have one type in use per device-key pair.⁴²

4.6.3 Security Procedures

This sub-clause gives message sequence charts for joining a secured network, authenticating a newly joined device, updating the network key, recovering the network key, establishing end-to-end application keys, and leaving a secured network.

42. CCB 1313

4.6.3.1 Joining a Secured Network

When a device prepares to join a secured network it shall set the AIB attribute *apsLinkKeyType* for its link key with the trust center according to the kind of key it has. If it is using the well-known default trust center link key, or another global link key, it shall set *apsLinkKeyType* to 0x01. If it is using a unique link key it shall set *apsLinkKeyType* to 0x00.⁴³

Figure 4.26 shows an example message sequence chart ensuing from when a joiner device communicates with a router device to join a secured network.

A device that is operating in a network and has missed a key update may also use these procedures to receive the latest network key.

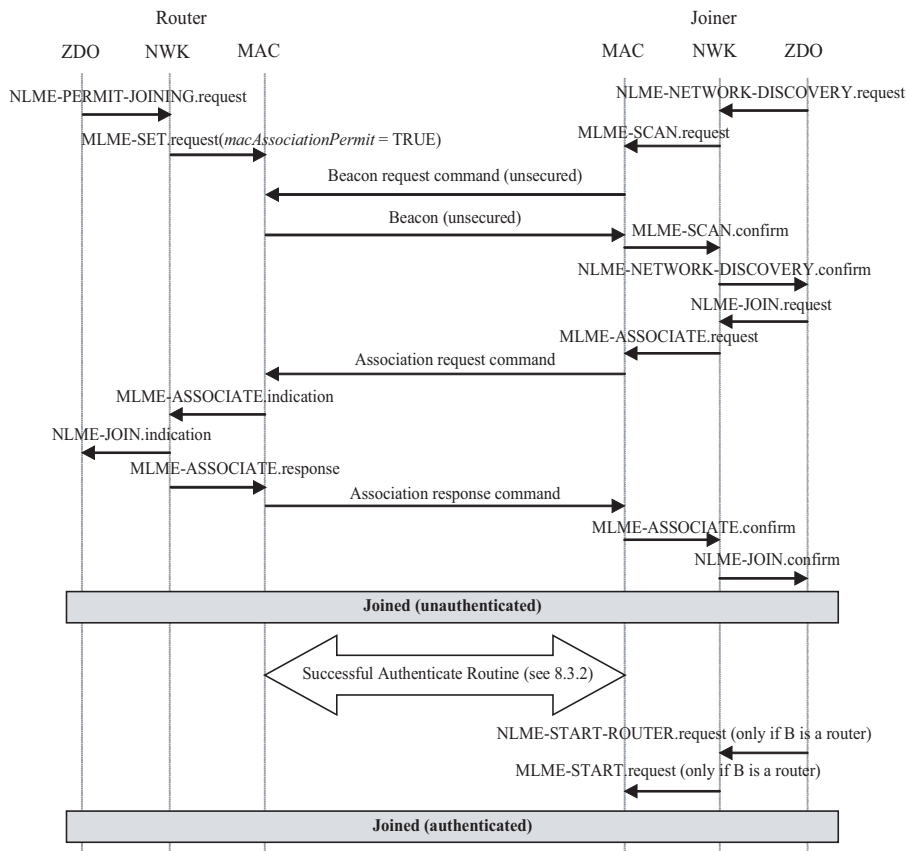


Figure 4.26 Example of Joining a Secured Network

43. CCB 1313

The joiner device may begin the join procedure by issuing an NLME-NETWORK-DISCOVERY.request primitive. This primitive will invoke an MLME-SCAN.request primitive which may cause the transmission of an unsecured beacon request frame (depending on whether the scan is an active or passive scan).

The joiner device receives beacons from nearby routers and the NWK layer issues an NLME-NETWORK-DISCOVERY.confirm primitive. The NetworkList parameter of this primitive will indicate all of the nearby PANs. In Figure 4.26, the shown router device has already been placed in a state such that its beacons have the “association permit” sub-field set to “1” (permit association).

The joiner device shall decide which PAN to join and shall issue the NLME-JOIN.request primitive to join that PAN. If the joiner already has a network key for this PAN, the SecurityEnable parameter for the NLME-JOIN.request primitive shall be set to TRUE; otherwise it shall be set to FALSE. As shown in Figure 4.26, the NLME-JOIN.request primitive causes an association request or rejoin request command to be sent to the router.

Upon receipt of an association request MAC command, the router shall issue an MLME-ASSOCIATE.indication primitive. Next, the NWK layer will issue an NLME-JOIN.indication primitive to the router’s ZDO. The router shall now know the joiner device’s address and security capabilities. The router will also issue an MLME-ASSOCIATE.response. This primitive will cause an association response command to be sent to the joiner.

Alternatively, upon receipt of a rejoin request network command, the NWK layer will issue an NLME-JOIN.indication primitive to the router’s ZDO. The router shall now know the joiner device’s address, security capabilities, and whether the network key was used to secure the rejoin request command. The router will also issue a rejoin response command to the joiner.

Upon receipt of the association response MAC command or the rejoin response network command, the joiner shall issue the NLME-JOIN.confirm primitive. The joiner is now declared “joined, but unauthenticated” to the network. The authentication routine (see sub-clause 4.6.3.2) shall follow.

If the joiner is not a router, it is declared “joined and authenticated” immediately following the successful completion of the authentication routine.

If the joiner is a router, it is declared “joined and authenticated” only after the successful completion of the authentication routine followed by the initiation of routing operations. Routing operations shall be initiated by the joiner’s ZDO issuing the NLME-START.request primitive to cause the MLME-START.request primitive to be sent to the MAC layer of the joiner.

If the router refuses the joiner, its association response frame or rejoin response frame shall contain the association status field set to a value other than 0x00, and,

after this parameter reaches the ZDO of the joiner in the NLME-JOIN.confirm primitive, the joiner shall not begin the authentication routine.

4.6.3.2 Authentication

Once a device joins a secured network and is declared “joined but unauthenticated”, it must be authenticated as specified in this sub-clause. In high security mode, neighboring routers must also be authenticated as described in sub-clause 4.4.8.

4.6.3.2.1 Router Operation

If the router is not the Trust Center, it shall begin the authentication procedure immediately after receipt of the NLME-JOIN.indication primitive by issuing an APSME-UPDATE-DEVICE.request primitive with the DestAddress parameter set to the *apsTrustCenterAddress* in the AIB and the DeviceAddress parameter set to the address of the newly joined device. The Status parameter of this primitive shall be set by the NLME-JOIN.indication primitive parameters according to Table 4.42.

Table 4.42 Mapping of NLME-JOIN.indication Parameters to Update Device Status

NLME-JOIN.indication Parameters			Update Device Status	
Capability Information Bit 6	Method (RejoinNetwork parameter)	Request Secured	Status	Description
0	NWK Rejoin (0x02)	TRUE	0x00	Standard security device secured rejoin
0	MAC Association (0x00)	FALSE	0x01	Standard security device unsecured join
0	NWK Rejoin (0x02)	FALSE ^a	0x03	Standard security device unsecured rejoin
1	NWK Rejoin (0x02)	TRUE ^b	0x04	High security device secured rejoin
1	MAC Association (0x00)	FALSE	0x05	High security device unsecured join
1	NWK Rejoin (0x02)	FALSE ^c	0x07	High security device unsecured rejoin

a. CCB 1387

b. CCB 1387

c. CCB 1387

If the router is the Trust Center, it shall begin the authentication procedure by simply operating as a Trust Center.

If initiated by the joining device, the router shall complete the authentication procedure by responding to an entity authentication initiated by the joining device by using APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the joining device address, the Action parameter set to respond, and the RandomChallenge parameter set to a new random value.

The router shall not forward messages to a child device, or respond to ZDO requests or NWK command requests on that child's behalf, while the value of the relationship field entry in the corresponding *nwkNeighborTable* in the NIB is 0x05 (unauthenticated child).

4.6.3.2.2 Trust Center Operation

The Trust Center role in the authentication procedure shall be activated upon receipt of an incoming update-device command or immediately after receipt of the NLME-JOIN.indication primitive (in the case where the router is the Trust Center). The Trust Center behaves differently depending on at least five factors:

- Whether the Trust Center decides to allow the new device to join the network (for example, the Trust Center is in a mode that allows new devices to join).
- Whether the Trust Center is operating in residential or commercial mode (see sub-clause 4.6.2.1 and sub-clause 4.6.2.2, respectively).
- If in standard security mode, whether the device is joining unsecured or secured and the security capabilities of the joining device as indicated by the Status sub-field of the update-device command.
- If in high security mode, whether the device is joining unsecured or secured, the security capabilities of the joining device as indicated by the Status sub-field of the update-device command and whether the Trust Center has a master key corresponding to the newly joined device.
- The *nwkSecureAllFrames* attribute of the NIB.
- The type of the current network key.

If, at any time during the authentication procedure, the Trust Center decides not to allow the new device to join the network (for example, a policy decision or a failed key-establishment protocol), it shall take actions to remove the device from the network. If the Trust Center is not the router of the newly joined device, it shall remove the device from the network by issuing the APSME-REMOVE-DEVICE.request primitive with the ParentAddress parameter set to the address of the router originating the update-device command and the ChildAddress parameter set to the address of the joined (but unauthenticated) device.

4.6.3.2.2.1 Standard Security Mode

After being activated for the authentication procedure, the Trust Center shall send the device the active network key by issuing the APSME-TRANSPORT-KEY.request primitive with the DestAddress parameter set to the address of the newly joined device, and the KeyType parameter set to 0x01 (that is, standard network key).

If the joining device already has the network key (that is, the Status sub-field of the update-device command is 0x00), the TransportKeyData sub-parameters shall be set as follows: the KeySeqNumber sub-parameter shall be set to 0, the NetworkKey sub-parameter shall be set to all zeros, the UseParent sub-parameter shall be set to FALSE, and the message shall be protected with the active NWK key. The use of an all zero key at other times is prohibited.

Otherwise, the KeySeqNumber sub-parameter shall be set to the sequence count value for the active network key and the NetworkKey sub-parameter shall be set to the active network key. The UseParent sub-parameter shall be set to FALSE if the Trust Center is the router; otherwise, the UseParent sub-parameter shall be set to TRUE and the ParentAddress sub-parameter shall be set to the address of the router originating the update-device command.

In the case of a joining device that is not pre-configured with an active network key, the issuance of this transport-key primitive will cause the active network key to be sent unsecured from the router to the newly joined device — security is assumed to be present here via non-cryptographic means — for example, by only sending this key once, at low power, immediately after external input to both router and joiner, that can guarantee secrecy and authenticity. If the joining device did not receive the key via the APSME-TRANSPORT-KEY.indication within the *apsSecurityTimeOutPeriod* since receiving the NLME-JOIN.confirm primitive, it shall reset and may choose to start the joining procedure again.

A default global trust center link key must be supported by the device if no other link key is specified by the application at the time of joining. This default link key shall have a value of 5A 69 67 42 65 65 41 6C 6C 69 61 6E 63 65 30 39 (ZigBeeAlliance09).⁴⁴

4.6.3.2.2.2 High Security Mode

After being activated for the authentication procedure, the Trust Center operation in commercial mode depends on if the device joining the network is preconfigured with a Trust Center master or link key.

If the Trust Center does not already share a master or link key with the newly joined device, it shall send the device a master or link key by issuing the APSME-TRANSPORT-KEY.request primitive with the DestAddress parameter set to the

44. CCB 1313

address of the newly joined device, and the KeyType parameter set to 0x00 or 0x04 (that is, Trust Center master or link key). The TransportKeyData sub-parameters shall be set as follows: the Key sub-parameter shall be set to Trust Center master or link key as appropriate, and the ParentAddress sub-parameter shall set to the address of the local device if the Trust Center is the router. Otherwise, the ParentAddress sub-parameter shall set to the address of the router originating the update-device command. The issuance of this primitive will cause the master key to be sent unsecured from the router to the newly joined device—security is assumed to be present here via non-cryptographic means — for example by only sending this key once, at low power, immediately after external input to both router and joiner, etc.

If a master key was sent, the Trust Center shall initiate the establishment of a link key by issuing the APSME-ESTABLISH-KEY.request primitive with the ResponderAddress parameter set to the address of the newly joined device and the KeyEstablishmentMethod set to 0x00 (that is, SKKE). Additionally, if the *nwkSecureAllFrames* attribute of the NIB is FALSE or if the Trust Center is the router, the UseParent parameter shall be set to FALSE. Otherwise, the UseParent parameter shall be set to TRUE and the ResponderParentAddress parameter shall be set to the address of the router originating the update-device command.

Upon receipt of the corresponding APSME-ESTABLISH-KEY.confirm primitive with Status equal to 0x00 (that is, success), the Trust Center shall send the new device the active network key by issuing the APSME-TRANSPORT-KEY.request primitive with the DestAddress parameter set to the address of the newly joined device, and the KeyType parameter to 0x06 (that is, high security network key transport). The TransportKeyData sub-parameters shall be set as follows:

- The KeySeqNumber sub-parameter shall be set to the sequence count value for the active network key.
- The NetworkKey sub-parameter shall be set to active network key.
- The UseParent sub-parameter shall be set to FALSE.

4.6.3.2.3 Joining Device Operation

After successfully joining or rejoining a secured network, the joining device shall participate in the authentication procedure described in this sub-clause. Following a successful authentication procedure, the joining device shall set the *nwkSecurityLevel* and *nwkSecureAllFrames* attributes in the NIB to the values indicated in the beacon from the router.

A joined and authenticated device in a secured network with *nwkSecureAllFrames* equal to TRUE shall always apply NWK layer security to outgoing (incoming) frames unless the frame is destined for (originated from) a newly joined but unauthenticated child. No such restrictions exist if *nwkSecureAllFrames* is equal to FALSE.

The joining device's participation in the authentication procedure depends on the state of the device. There are at least four possible initial states to consider:

- Preconfigured with an active network key (that is, standard security mode).
- Preconfigured with a Trust Center link key and address (that is, standard security mode).
- Preconfigured with a Trust Center master key and address (that is, high security mode).
- Not preconfigured (that is, undetermined mode — either standard or high security mode).

In a secured network, if the device does not become authenticated within a preconfigured amount of time, it shall leave the network (see sub-clause 4.6.3.3).

4.6.3.2.3.1 Preconfigured Network Key

If the joining device was preconfigured with only an active network key (and if joining was successful), it shall set the outgoing frame counter for this key to zero, and empty the incoming frame counter set for this key, then wait to receive a dummy (all zero) network key from the Trust Center. The use of an all zero key at other times is prohibited. Upon receipt of the APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x01 (that is, the standard network key), the joining device shall set the *apsTrustCenterAddress* attribute in its AIB to the SrcAddress parameter of the APSME-TRANSPORT-KEY.indication primitive. The joining device is now considered authenticated and shall enter the normal operating state for standard security mode.

4.6.3.2.3.2 Preconfigured Trust Center Link Key

If the joining device is preconfigured only with a Trust Center link key and address (that is, the *apsTrustCenterAddress* attribute in the AIB) it shall wait to receive an active network key from the Trust Center. Upon receipt of the APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x01 (that is, the standard network key), the joining device shall set the *apsTrustCenterAddress* attribute in its AIB to the SrcAddress parameter of the APSME-TRANSPORT-KEY.indication primitive. The joining device is now considered authenticated and shall enter the normal operating state for standard security mode.

4.6.3.2.3.3 Preconfigured Trust Center Master Key

If the joining device is preconfigured with a Trust Center master key and address (that is, the *apsTrustCenterAddress* attribute in the AIB) it shall wait to establish a link key and receive an active network key from the Trust Center. Therefore, upon receipt of the APSME-ESTABLISH-KEY.indication primitive with the

InitiatorAddress parameter set to the Trust Center's address and the KeyEstablishmentMethod parameter set to SKKE, the joining device shall respond with the APSME-ESTABLISH-KEY.response primitive with the InitiatorAddress parameter set to the Trust Center's address and the Accept parameter set to TRUE. After receipt of the APSME-ESTABLISH-KEY.confirm primitive with the Address parameter set to the Trust Center's address and the Status parameter set to 0x00 (that is, success), the joining device shall expect to receive the active network key. If the joining device does not receive the APSME-ESTABLISH-KEY.indication primitive with the InitiatorAddress parameter set to the Trust Center's address and the KeyEstablishmentMethod parameter set to SKKE within *apsSecurityTimeOutPeriod*, or if the joining device fails to receive an expected response message to any APSME-ESTABLISH-KEY primitives or SKKE scheme messages it initiated, within *apsSecurityTimeOutPeriod*, it shall reset and may choose to start the joining procedure again.

If a joining device has a Trust Center link key, upon receipt of the APSME-TRANSPORT-KEY.indication primitive with SourceAddress parameter set to the Trust Center's address and with the KeyType parameter set 0x05 (that is, a high security network key), the device shall use the data in the TransportKeyData parameter to configure the active network key.

The authentication procedure shall be completed by the joining device initiating an entity authentication with the router by using the APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the router address, the Action parameter set to initiate, and the RandomChallenge parameter set to a new random value. The router will then respond with an APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the joining device address, the Action parameter set to respond, and the RandomChallenge parameter set to a new random value.

The joining device is now considered authenticated and shall enter the normal operating state for high security mode.

4.6.3.2.3.4 Not Preconfigured

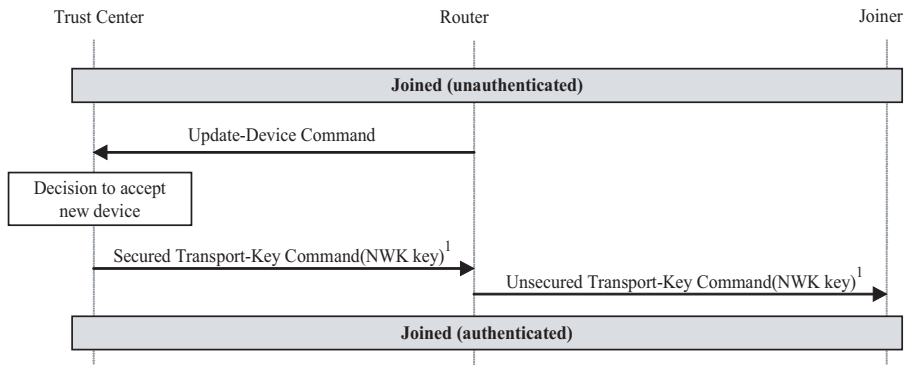
If the joining device is not preconfigured with an active network key, nor a Trust Center master or link key and address (that is, the *apsTrustCenterAddress* attribute in the AIB), it shall wait to receive either an unsecured Trust Center master or link key or an active network key. Implementers should note that transmission of an unsecured key represents a security risk and that if security is a concern, keys should be preconfigured – preferably via an out-of-band mechanism that guarantees secrecy and authenticity. If the joining device does not receive any of the keys within *apsSecurityTimeOutPeriod*, of receiving the NLME-JOIN.confirm primitive, it shall reset and may choose to start the joining procedure again.

Upon receipt of the APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x01 (that is, a standard network key), the joining device shall make the data in the TransportKeyData parameter its active network key and shall set the *apsTrustCenterAddress* attribute in its AIB to the SrcAddress parameter of the APSME-TRANSPORT-KEY.indication primitive. The joining device is now considered authenticated and shall enter the normal operating state for standard security mode.

Upon receipt of the APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x04 (that is, the Trust Center link key), the joining device shall make its Trust Center link key the data in the TransportKeyData parameter and the *apsTrustCenterAddress* attribute in its AIB the SrcAddress parameter. If the APSME-TRANSPORT-KEY.indication primitive SourceAddress parameter is set to the Trust Center's address and the KeyType parameter is set to 0x01 (that is, the standard network key), the joining device shall use the data in the TransportKeyData parameter to configure the active network key. All incoming frame counters and the outgoing frame counter of the active network key shall be set to 0. The joining device is now considered authenticated and shall enter the normal operating state for standard security mode.

Upon receipt of the APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x00 (that is, the Trust Center master key), the joining device shall make its Trust Center master key the data in the TransportKeyData parameter and the *apsTrustCenterAddress* attribute in its AIB the SrcAddress parameter. Next, upon receipt of the APSME-ESTABLISH-KEY.indication primitive with the InitiatorAddress parameter set to the Trust Center's address and the KeyEstablishmentMethod parameter set to SKKE, the joining device shall respond with the APSME-ESTABLISH-KEY.response primitive with the InitiatorAddress parameter set to the Trust Center's address and the Accept parameter set to TRUE. After receipt of the APSME-ESTABLISH-KEY.confirm primitive with the Address parameter set to the Trust Center's address and the Status parameter set to 0x00 (that is, success), the joining device shall expect to receive the active network key. If the APSME-TRANSPORT-KEY.indication primitive is SourceAddress parameter is set to the Trust Center's address and the KeyType parameter is set to 0x05 (that is, the high security network key), the joining device shall use the data in the TransportKeyData parameter to configure the active network key. The authentication procedure shall be completed by the joining device initiating an entity authentication with the router by using APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the router address, the Action parameter set to initiate, and the RandomChallenge parameter set to a new random value. The router will then respond with a APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the joining device address, the Action parameter set to respond, and the RandomChallenge

parameter set to a new random value. The joining device is now considered authenticated and shall enter the normal operating state for commercial mode.



Note:

1. The trust center sends a dummy all-zero NWK key if the joiner securely joined using a preconfigured network key.

Figure 4.27 Example Standard Security Mode Authentication Procedure

4.6.3.2.4 Neighboring Device Authentication

If a neighboring device attempts to communicate and the neighboring device is unknown and the device is in high security mode and frame counter checking is in place, the communication will be rejected as the frame counter has not been initialized. The neighboring device shall be authenticated by initiating an entity authentication with the it by using APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the neighboring device address, the Action parameter set to initiate, and the RandomChallenge parameter set to a new random value. The APSME-AUTHENTICATION.request will be sent with random jitter. The neighboring device will then respond with a APSME-AUTHENTICATION.request with the PartnerAddress parameter set to the device address, the Action parameter set to respond, and the RandomChallenge parameter set to a new random value. The neighboring device is now considered authenticated.

4.6.3.2.5 Message Sequence Charts

Figure 4.27 and 4.28 give example message sequence charts for the authentication procedure when the router and the Trust Center are separate devices operating in standard or high security mode, respectively.

In Figure 4.27 the update-device and transport-key commands communicated between the Trust Center and the router shall be secured at the APS layer based on the active network key. The transport-key command sent from the router to the joiner shall not be secured.

In Figure 4.28, the update-device and transport-key commands communicated between the Trust Center and the router shall be secured at the APS layer based on the Trust Center link key. If the *nwkSecureAllFrames* NIB attribute is TRUE, it is also secured at the NWK layer with the active network key. The transport-key command sent from the router to the joiner shall not be secured. The SKKE commands shall be sent using the router as a liaison when the *nwkSecureAllFrames* NIB attribute is TRUE, such that SKKE commands between the Trust Center and the router shall be secured at the NWK layer with the active network key and commands between the router and the joiner shall not be secured. Otherwise, the SKKE commands shall be unsecured between the Trust Center and the joiner. The final transport-key communicated between the Trust Center and the joiner shall be secured at the APS layer, based on the Trust Center link key and, if the *nwkSecureAllFrames* NIB attribute is TRUE, also secured at the NWK layer with the active network key.

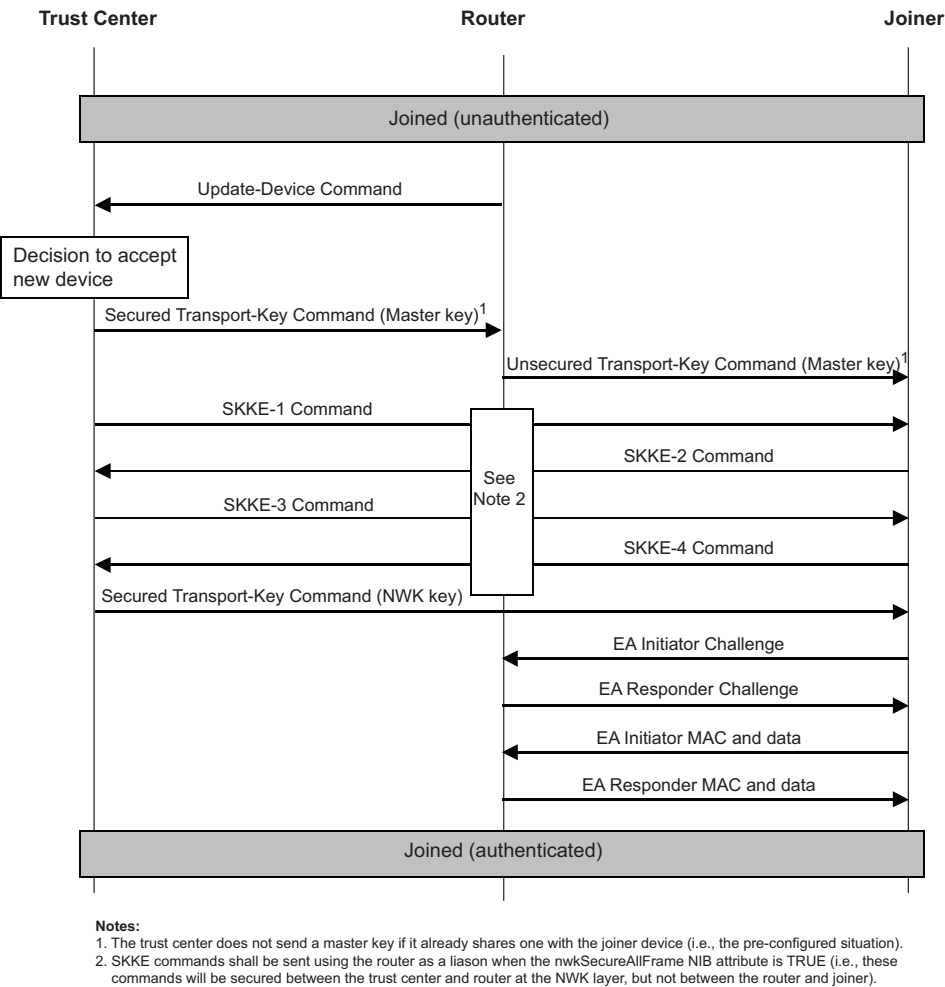


Figure 4.28 Example High Security Mode Authentication Procedure

4.6.3.3 Intra-PAN Portability

Devices shall follow the procedures described in this sub-clause as necessary to support portability, in conjunction with the mechanism described in sub-clause 2.5.5.5.2.2.

At present, the security support for intra-PAN portability is minimized. In most cases security operation is not different from normal, as described in these sections.

4.6.3.3.1 Router Operation

This text describes the security operations for support of intra-PAN security which are to be carried out by the ZigBee coordinator and by ZigBee routers.

Following the steps described in sub-clause 2.5.5.5.2.2, an orphaned device shall be provisionally accepted onto the network for at least *apsSecurityTimeOutPeriod* milliseconds. During this period it shall be required to send at least one correctly formed ZigBee message secured with the network key to the new parent. If this message successfully passes all the security processing steps described in this document, it shall be accepted as a member of the network.

This specification neither specifies nor requires any action from the parent in the case that a message from an orphaned device fails security processing above that required by text elsewhere in this document.

4.6.3.3.2 End-Device Operation

Following the steps described in sub-clause 2.5.5.5.2.2, an orphaned device shall be provisionally accepted onto the network for at least *apsSecurityTimeOutPeriod* milliseconds. During this period, it shall be required to send at least one ZigBee message, secured with the network key to the new parent. Further, it shall verify that at least one ZigBee message, secured using the current network key is received from the new parent. If this message successfully passes all the security processing steps described in this document, the device shall operate as a member of the network. If this protocol cannot be completed correctly, the device shall abandon this attempt to rejoin the network using this parent.

As normal, when operating in standard security mode the end device shall not accept an unsecured network key from the Trust Center, except as required by this document when activated to join a new network.

As normal, when operating in high security mode the end device shall be configured to accept an updated network key from the Trust Center, even when not activated for the authentication procedure. In this case, the key shall be transported using the APSME-TRANSPORT-KEY.request primitive, and appropriate security shall be verified.

Note that a ZigBee router may also carry out an orphan scan as described in sub-clause 2.5.5.5.2.2. In this case it shall, at this time, also follow the steps described in this sub-section.

4.6.3.4 Network Key Update

The Trust Center and network devices shall follow the procedures described in this sub-clause when updating the active network key.

4.6.3.4.1 Trust Center Operation

When updating a standard network key with a new key of the same type, the Trust Center may broadcast the new key to all devices on the network by issuing the APSME-TRANSPORT-KEY.request primitive with the DestAddress parameter set to the broadcast address and the KeyType parameter set to 0x01 (that is, a standard network key). The TransportKeyData sub-parameters shall be set as follows:

- The KeySeqNumber sub-parameter shall be set to the sequence count value for the new network key.
- The NetworkKey sub-parameter shall be set to the new network key.
- The UseParent sub-parameter shall be set to FALSE.

If the sequence count for the previously distributed network key is represented as N , then the sequence count for this new network key shall be $(N+1) \bmod 256$. The Trust Center may cause a switch to this new key by issuing the APSME-SWITCH-KEY.request primitive with the DestAddress parameter set to the broadcast address and the KeySeqNumber parameter set to the sequence count value for the updated network key.

In standard security mode, the Trust Center may maintain a list of all of the devices in the network; in high security mode, the Trust Center shall maintain such a list. To update the active network key using this list, the Trust Center shall first send the new network key to each device on this list and then ask each device to switch to the new key. The new network key shall be sent to a device on the list by issuing the APSME-TRANSPORT-KEY.request primitive with the DestAddress parameter set to the address of the device on the list and the KeyType parameter set to 0x05 (that is, a high security network key). The TransportKeyData sub-parameters shall be set as follows:

- The KeySeqNumber sub-parameter shall be set to the sequence count value for the new network key.
- The NetworkKey sub-parameter shall be set to the new network key.
- The UseParent sub-parameter shall be set to FALSE.

If the sequence count for the previously distributed network key is represented as N , then the sequence count for this new network key shall be $(N+1) \bmod 256$. The Trust Center shall ask a device to switch to this new key by issuing the APSME-SWITCH-KEY.request primitive with the DestAddress parameter set to the address of the device and the KeySeqNumber parameter set to the sequence count value for the updated network key.

4.6.3.4.2 Network Device Operation

When in the normal operating state and upon receipt of a APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x01 or 0x05 (that is, a network key), a device shall accept the TransportKeyData parameters as a network key only if the SrcAddress parameter is the same as the Trust Center's address (as maintained in the *apsTrustCenterAddress* attribute of the AIB). If accepted and if the device is capable of storing an alternate network key, the key and sequence number data contained in the TransportKeyData parameter shall replace the alternate network key. Otherwise, the key and sequence number data contained in the TransportKeyData parameter shall replace the active network key. In either case, all incoming frame counters and the outgoing frame counter of the appropriate network key shall be set to 0.

When in the normal operating state and upon receipt of a APSME-SWITCH-KEY.indication primitive, a device shall switch its active network key to the one designated by the KeySeqNumber parameter only if the SrcAddress parameter is the same as the Trust Center's address (as maintained in the *apsTrustCenterAddress* attribute of the AIB).

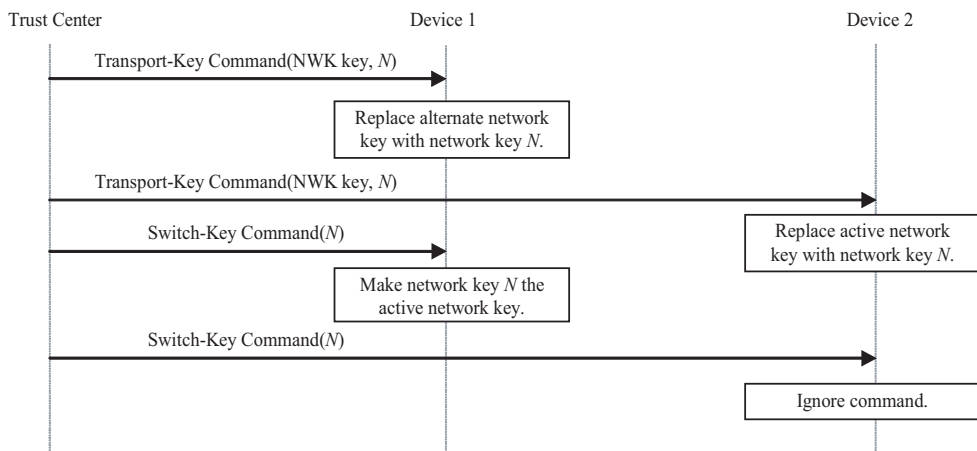


Figure 4.29 Example Network Key-Update Procedure

4.6.3.4.3 Message Sequence Chart

An example of a successful network key-update procedure for two devices is shown in Figure 4.29. In this example, the Trust Center sends a network key with sequence number *N* to devices 1 and 2. In this example, device 1 is an FFD capable of storing two network keys, an active and alternate, and device 2 is an RFD that can store only a single network key. Upon receipt of the transport-key command, device 1 replaces its alternate network key with the new network key; however device 2 must replace its active network key with the new key. Next,

upon receipt of the switch-key command, device 1 makes the new network key the active network key; however device 2 has only one active network key, so it ignores this command.

4.6.3.5 End-to-End Application Key Establishment

An initiator device, a Trust Center, and a responder device shall follow the procedures described in this sub-clause when establishing a link key for purposes of end-to-end application security between initiator and responder devices.

4.6.3.5.1 Device Operation

The initiator device shall begin the procedure to establish a link key with a responder device by issuing the APSME-REQUEST-KEY.request primitive. The DestAddress parameter shall be set to the address of its Trust Center, the KeyType parameter shall be set to 0x02 (that is, application key), and the PartnerAddress parameter shall be set to the address of the responder device.

4.6.3.5.1.1 Upon Receipt of a Link Key

Upon receipt of an APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x03 (that is, application link key), a device may accept the TransportKeyData parameters as a link key with the device indicated by the PartnerAddress parameter only if the SrcAddress parameter is the same as the *apsTrustCenterAddress* attribute of the AIB. If accepted, the *apsDeviceKeyPairSet* attribute in AIB table will be updated. A key-pair descriptor in the AIB shall be created (or updated if already present) for the device indicated by the PartnerAddress parameter, by setting the DeviceAddress element to the PartnerAddress parameter, the LinkKey element to the link key from the TransportKeyData parameter, and the OutgoingFrameCounter and IncomingFrameCounter elements to 0.

4.6.3.5.1.2 Upon Receipt of a Master Key

Upon receipt of an APSME-TRANSPORT-KEY.indication primitive with the KeyType parameter set to 0x02 (that is, application master key), a device may accept the TransportKeyData parameters as a master key with the device indicated by the PartnerAddress sub-parameter only if the SrcAddress parameter is the same as the *apsTrustCenterAddress* attribute of the AIB. If accepted, the *apsDeviceKeyPairSet* attribute in AIB table will be updated. A key-pair descriptor shall be created (or updated if already present) for the device indicated by the PartnerAddress parameter, by setting the DeviceAddress element to the PartnerAddress parameter, the MasterKey element to the master key from the TransportKeyData parameter, and the OutgoingFrameCounter and IncomingFrameCounter elements to 0.

Next, if the Initiator sub-parameter of the TransportKeyData parameter of the APSME-TRANSPORT-KEY.indication primitive was TRUE, the device shall issue the APSME-ESTABLISH-KEY.request primitive. The ResponderAddress parameter shall be set to the PartnerAddress sub-parameter of the TransportKeyData parameter, the UseParent parameter shall be set to FALSE, and the KeyEstablishmentMethod parameter shall be set to 0x00 (that is, SKKE).

Upon receipt of the APSME-ESTABLISH-KEY.indication primitive, the responder device shall be informed that the initiator device wishes to establish a link key. If the responder decides to establish a link key, it shall issue the APSME-ESTABLISH-KEY.response primitive with the InitiatorAddress parameter set to the address of the initiator and the Accept parameter set to TRUE. Otherwise, it shall set the Accept parameter set to FALSE.

If the responder decided to set up a key with the initiator, the SKKE protocol will ensue and the APSME-ESTABLISH-KEY.confirm primitive will be issued to both the responder and initiator.

4.6.3.5.2 Trust Center Operation

Upon receipt of APSME-REQUEST-KEY.indication primitives with the KeyType parameter set to 0x02 (that is, application key), the Trust Center behavior depends on whether it has been configured to send out application link keys or master keys.

The Trust Center shall issue two APSME-TRANSPORT-KEY.request primitives. If configured to send out application link keys the KeyType parameter shall be set to 0x03 (that is, application link key); otherwise, the KeyType parameter shall be set to 0x02 (that is, application master key). The first primitive shall have the DestAddress parameter set to the address of the device requesting the key. The TransportKeyData sub-parameters shall be set as follows:

- The PartnerAddress sub-parameter shall be set to the PartnerAddress sub-parameter of the APSME-REQUEST-KEY.indication primitive's TransportKeyData parameter.
- The Initiator sub-parameter shall be set to TRUE.
- The Key sub-parameter shall be set to a new key K (a master or link key).

The key shall have been generated in a random fashion. The second primitive shall have the DestAddress parameter set to the PartnerAddress sub-parameter of the APSME-REQUEST-KEY.indication primitive's TransportKeyData parameter. The TransportKeyData sub-parameters shall be set as follows:

- The PartnerAddress sub-parameter shall be set to the address of the device requesting the key.
- The Initiator sub-parameter shall be set to FALSE.
- The Key sub-parameter shall be set to K.

4.6.3.5.3 Message Sequence Chart

An example message sequence chart of the end-to-end application key establishment procedure is shown in Figure 4.30. The procedure begins with the transmission of the request-key command from the initiator to the Trust Center. Next, the Trust Center starts a time-out timer. For the duration of this timer (that is, until it expires), the Trust Center shall discard any new request-key commands for this pair of devices unless they are from the initiator.

The Trust Center shall now send transport-key commands containing the application link or master key to the initiator and responder devices. Only the initiator's transport-key command will have the Initiator field set to 1 (that is, TRUE), so if a master key was sent, only the initiator device will begin the key-establishment protocol by sending the SKKE-1 command. If the responder decides to accept establishing a key with the initiator, the SKKE protocol will progress via the exchange of the SKKE-2, SKKE-3, and SKKE-4 commands. Upon completion (or time-out), the status of the protocol is reported to the ZDOs of the initiator and responder devices. If successful, the initiator and responder will now share a link key and secure communications will be possible.

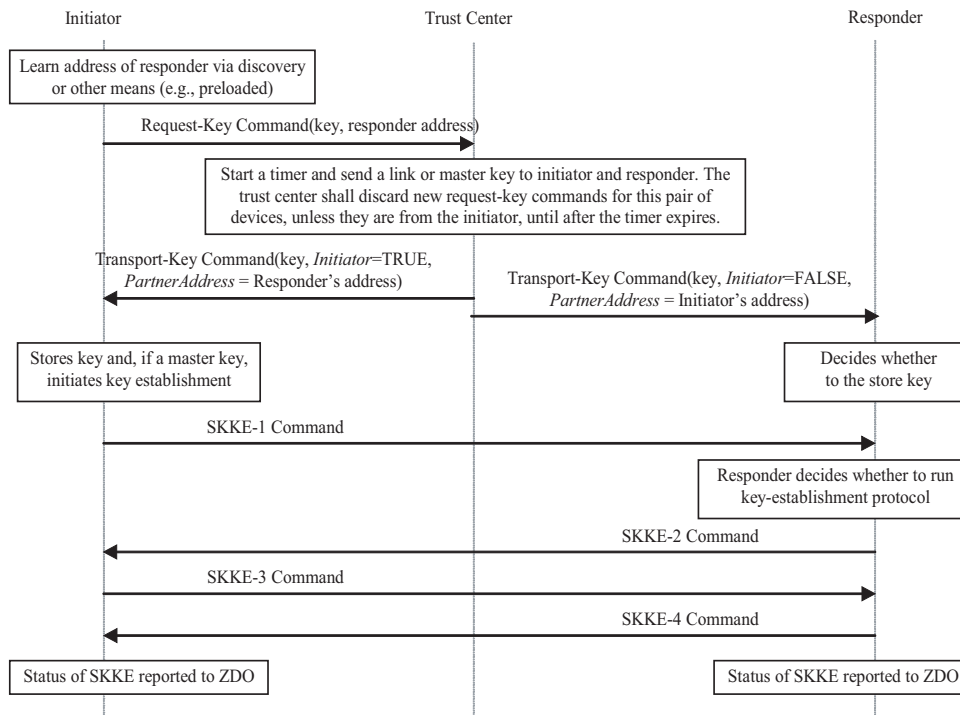


Figure 4.30 Example End-to-End Application Key Establishment Procedure

4.6.3.6 Network Leave

A device, its router, and the Trust Center shall follow the procedures described in this sub-clause when the device is to leave the network.

4.6.3.6.1 Trust Center Operation

If a Trust Center wants a device to leave and if the Trust Center is not the router for that device, the Trust Center shall issue the APSME-REMOVE-DEVICE.request primitive, with the ParentAddress parameter set to the router's address and the ChildAddress parameter set to the address of the device it wishes to leave the network.

The Trust Center will also be informed of devices that leave the network. Upon receipt of an APSME-UPDATE-DEVICE.indication primitive with the Status parameter set to 0x02 (that is, device left), the DeviceAddress parameter shall indicate the address of the device that left the network and the SrcAddress parameter shall indicate the address of parent of this device. If operating in high security mode, the Trust Center shall delete the leaving device from its list of network devices.

4.6.3.6.2 Router Operation

Routers are responsible for receiving remove-device commands and for sending update-device commands.

Upon receipt of an APSME-REMOVE-DEVICE.indication primitive, if the SrcAddress parameter is equal to the *apsTrustCenterAddress* attribute of the AIB then the command shall be accepted. The router shall ignore APSME-REMOVE-DEVICE.indication primitives with the SrcAddress parameter not equal to the *apsTrustCenterAddress* attribute of the AIB.

If the DeviceAddress corresponds to the local device's address, then the device shall remove itself from the network according to sub-clause 4.6.3.6.3. If the DeviceAddress corresponds to address of a child device then a router shall issue an NLME-LEAVE.request primitive with the DeviceAddress parameter the same as the DeviceAddress parameter of the APSME-REMOVE-DEVICE.indication primitive and the rejoin parameter set to 0. Other fields are defined by the stack profile.

If the DeviceAddress does not correspond to the local device address, nor does it correspond to a child device of the router, the command shall be discarded.⁴⁵

Upon receipt of an NLME-LEAVE.indication primitive with the DeviceAddress parameter set to one of its children, a router that is not also the Trust Center shall issue an APSME-UPDATE-DEVICE.request primitive with:

45. CCB 1280

- The DstAddress parameter set to the address of the Trust Center.
- The Status parameter set to 0x02 (that is, device left).
- The DeviceAddress parameter set to the DeviceAddress parameter of the NLME-LEAVE.indication primitive.

If the router is the Trust Center, it should simply operate as the Trust Center and shall not issue the APSME-UPDATE-DEVICE.request primitive (see sub-clause 4.6.3.6.1).

4.6.3.6.3 Leaving Device Operation

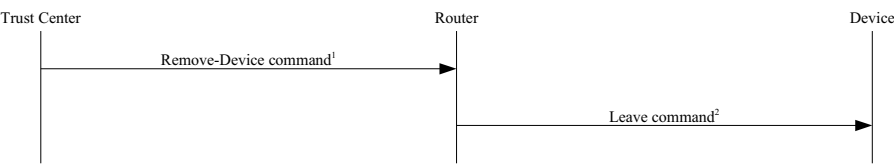
Devices are responsible for receiving and sending leave commands.

In a secured ZigBee network, leave commands shall be secured with the active network key and sent with security enabled at the level indicated by the *nwkSecurityLevel* attribute in the NIB.

In a secured ZigBee network, leave commands shall be received and processed only if secured with the active network key and received with security enabled at the level indicated by the *nwkSecurityLevel* attribute in the NIB.

4.6.3.6.4 Message Sequence Charts

Figure 4.31 shows an example message sequence chart in which a Trust Center asks a router to remove one of its children from the network. If a Trust Center wants a device to leave and if the Trust Center is not the router for that device, the Trust Center shall send the router a remove-device command with the address of the device it wishes to leave the network. In a secure network, the remove-device command shall be secured with a link key if present; otherwise shall be secured with the active network key. Upon receipt of the remove-device command, a router shall send a leave command to the device to leave the network.

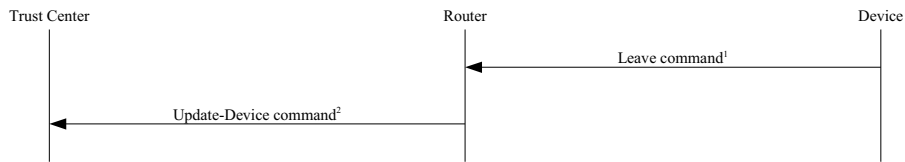


- Note:
1. If a trust center wants a device to leave and if the trust center is not the router for that device, the trust center shall send the router a remove-device command with the address of the device it wishes to leave the network.
 2. A router shall send a leave command to cause one of its children to leave the network.

Figure 4.31 Example Remove-Device Procedure

Figure 4.32 shows an example message sequence chart whereby a device notifies its router that it is leaving the network. In this example, the device sends a leave command (secured with the active network key) to its router. The router then

sends a update-device command to the Trust Center. In a secured network, the update-device command must be secured with the link key, if present, or the active network key.



Note:

1. A device leaving the network shall send a leave command to its router

2. Upon receipt of a valid leave command, a router shall send an update-device command to the trust center to inform it that a device has left the network.

Figure 4.32 Example Device-Leave Procedure

4.6.3.6.5 Trust Center Operation

In this specification, there is no special additional role for the Trust Center above that of other routing devices.

As normal, when operating in standard security mode the Trust Center shall not issue or reissue a network key unsecured to orphaned devices, except when activated for the authentication procedure.

As normal, when operating in high security mode the Trust Center may optionally issue or reissue the current or an updated network key to orphaned devices when not activated for the authentication procedure. In this case, the key shall be transported using the APSME-TRANSPORT-KEY.request primitive, and shall be secured appropriately. Initiation of such an update is beyond the scope of this specification.

4.6.3.7 Command Tunnelling

Devices shall follow the procedures described in this sub-clause to allow secure communication between the Trust Center and a remote device that does not have the current network key.

4.6.3.7.1 Trust Center Operation

To embed a command in a tunnel command, the Trust Center shall first apply security protection as specified in sub-clause 4.4.1.1 and then, if security processing succeeds, the secured command frame shall be embedded in a Tunnel command frame as follows:

- 1 The APS header fields shall be set to the values of the APS header fields of the command to be embedded.

- 2 The destination address field shall be set to the 64-bit extended address of the destination device.
- 3 The tunnelled auxiliary frame field shall be set to the auxiliary frame of the secured command, with following changes:
 - The extended nonce sub-field shall be set to 1;
 - The source address field shall be set to the 64-bit extended address of the Trust Center;
 - The tunnelled command shall be set to the secured payload of the embedded command.

The tunnelled command shall then be sent to the parent or other neighbor of the destination device.

4.6.3.7.2 Parent Operations

Upon receipt of an APS tunnel command, a router shall extract the embedded command as follows:

- 1 The APS header fields shall be set to the values of the APS header fields of the tunnel command.
- 2 The auxiliary frame field shall be set to the value of the tunnelled auxiliary frame field of the tunnel command.
- 3 The APS payload field shall be set to the tunnelled command field of the tunnel command.

The extracted command shall be sent to the destination indicated by the destination address field by issuing the NLDE-DATA.request primitive with security disabled.

4.6.3.7.3 Destination Operation

Upon receipt of a message secured at the APS layer and with an extended nonce in the APS auxiliary frame, the message shall be processed as usual, except that the message shall not be looked up in, or added to, the APS duplicate rejection table.

4.6.3.8 Permissions Configuration Table

The permissions configuration table in Table 4.43 indicates which devices have authorization to carry out certain types of commands, and determines in each case whether or not link key security is required. Values in the table are expected to be populated by the next higher layer, and are checked as indicated below for

incoming commands. If an incoming command is not permitted, then it shall not be carried out, and an error message may be sent to the source.

Table 4.43 Elements of the Permissions Configuration Table

Name	Type	Range	Description	Default
ModifyPermissionsConfigurationTable	Permissions descriptor, see Table 4.44.	-	Permission to modify this table.	-
NetworkSettings	Permissions descriptor, see Table 4.44.	-	Permission to configure network startup and join parameters, including direct join, permit join, leave, network maintenance and reset.	-
ApplicationSettings	Permissions descriptor, see Table 4.44.	-	Permission to configure application settings, including bindings and groups, and other application configuration commands.	-
SecuritySettings	Permissions descriptor, see Table 4.44.	-	Permission to configure security settings.	-
ApplicationCommands	Permissions descriptor, see Table 4.44.	-	Permission to issue application layer commands.	-
Reserved	Permissions descriptor, see Table 4.44.	-	Reserved.	-
Reserved	Permissions descriptor, see Table 4.44.	-	Reserved.	-
SKKEWithMasterKey	List of device addresses.	Any valid 64-bit address or 0xFFFFFFFFFFFFFFFF	Permission to use SKKE to generate a new trust centre link key, where supported.	-

Table 4.44 Elements of the Permissions Descriptor

Name	Type	Range	Description	Default
AuthorizedDeviceList	List of device addresses	-	List of valid 64-bit addresses for each allowed devices or single entry of 0xFFFFFFFFFFFFFFFF indicating all devices are allowed.	0xFFFFFFFFFFFFFFFF
LinkKeyRequired	Boolean	TRUE | FALSE	Indicates whether a link key is required to accept command.	FALSE

4.6.3.8.1 Services

The groups of services listed in the permissions configuration table are described in detail here.

- The ModifyPermissionsConfigurationTable entry is available to be used by the next higher layer to determine whether a request to modify this table is permitted.
- The NetworkSettings entry shall be used by the ZDO, and optionally by the next higher layer, to determine whether certain networking-related configuration commands are permitted. The ZDO commands which shall be subject to this table entry are the Mgmt_Direct_Join_req, Mgmt_Permit_Join_req, and Mgmt_Leave_req commands.
- The ApplicationSettings entry shall be used by the ZDO, and optionally by the next higher layer, to determine whether certain application-related configuration commands are permitted. The ZDO commands which shall be subject to this table entry are the Bind_req and Unbind_req commands.
- The SecuritySettings entry is available to be used by the next higher layer to determine whether specified security-related configuration commands are permitted.
- The ApplicationCommands entry is available to be used by the next higher layer to determine whether specified application commands are permitted.
- The SKKEWithMasterKey entry shall be used to optionally restrict which devices are permitted to initiate an SKKE transaction using the Trust Center master key, in order to generate a new Trust Center link key. This table entry has no effect on devices where SKKE is not implemented.

4.6.3.8.2 Usage Details

Incoming commands shall invoke a permissions check where specified, and on failure the incoming command shall not be carried out. Any error message sent on failure of a permissions check shall be defined in the specification of the relevant command.

The AuthorizedDevicesList of each entry shall contain a list of the IEEE addresses of authorized devices, or alternatively may contain only the value 0xFFFFFFFFFFFFFFFF, indicating that all devices are permitted to carry out the corresponding commands if properly secured.

Where specified above, table entries can be checked by higher layers in addition to any checks mandated within this specification. The details of higher layer checks and any associated error messages are beyond the scope of this specification.

Incoming commands secured with the Trust Center link key are assumed to come from the Trust Center, and so are exempt from all the checks described here, and shall always be permitted if properly secured. This exemption has no effect for devices without a Trust Center link key.

This table is optional and where supported shall contain an empty set for the ModifyPermissionsConfigurationTable and SKKEWithMasterKey entries, to indicate that these services cannot be used, and all other entries shall have the AuthorizedDeviceList entry of the permissions descriptor set to a single value of 0xFFFFFFFFFFFFFFFF to indicate that no devices are restricted.

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CCM* MODE OF OPERATION

CCM* is a generic combined encryption and authentication block cipher mode. CCM* is only defined for use with block ciphers having a 128-bit block size, such as AES-128 [B8]. The CCM* principles can easily be extended to other block sizes, but doing so will require further definitions.

The CCM* mode coincides with the original CCM mode specification [B21] for messages that require authentication and, possibly, encryption, but does also offer support for messages that require only encryption. As with the CCM mode, the CCM* mode requires only one key. The security proof for the CCM mode([B22] and [B23]) carries over to the CCM* mode described here. The design of the CCM* mode takes into account the results of [B24], thus allowing it to be securely used in implementation environments in which the use of variable-length authentication tags, rather than fixed-length authentication tags only, is beneficial.

Prerequisites: The following are the prerequisites for the operation of the generic CCM* mode:

- 1 A block-cipher encryption function E shall have been chosen, with a 128-bit block size. The length in bits of the keys used by the chosen encryption function is denoted by $keylen$.
- 2 A fixed representation of octets as binary strings shall have been chosen (for example, most-significant-bit first order or least-significant-bit-first order).
- 3 The length L of the message length field, in octets, shall have been chosen. Valid values for L are the integers 2, 3,..., 8 (the value $L=1$ is reserved).
- 4 The length M of the authentication field, in octets, shall have been chosen. Valid values for M are the integers 0, 4, 6, 8, 10, 12, 14, and 16. (The value $M=0$ corresponds to disabling authenticity, since then the authentication field contains an empty string.)

A.1 Notation and Representation

Throughout this specification, the representation of integers as octet strings shall be fixed. All integers shall be represented as octet strings in most-significant-octet first order. This representation conforms to the conventions in Section 4.3 of ANSI X9.63-2001 [B7].

A.2 CCM* Mode Encryption and Authentication Transformation

The CCM* mode forward transformation involves the execution, in order, of an input transformation (A.2.1), an authentication transformation (A.2.2), and encryption transformation (A.2.3).

Input: The CCM* mode forward transformation takes as inputs:

- 1 A bit string *Key* of length *keylen* bits to be used as the key. Each entity shall have evidence that access to this key is restricted to the entity itself and its intended key-sharing group member(s).
- 2 A nonce *N* of 15-*L* octets. Within the scope of any encryption key *Key*, the nonce value shall be unique.
- 3 An octet string *m* of length *l(m)* octets, where $0 \leq l(m) < 28L$.
- 4 An octet string *a* of length *l(a)* octets, where $0 \leq l(a) < 2^{64}$.

The nonce *N* shall encode the potential values for *M* such that one can uniquely determine from *N* the value of *M* actually used. The exact format of the nonce *N* is outside the scope of this specification and shall be determined and fixed by the actual implementation environment of the CCM* mode.

Note: The exact format of the nonce *N* is left to the application, to allow simplified hardware and software implementations in particular settings. Actual implementations of the CCM* mode may restrict the values of *M* that are allowed throughout the life-cycle of the encryption key *Key* to a strict subset of those allowed in the generic CCM* mode. If so, the format of the nonce *N* shall be such that one can uniquely determine from *N* the actually used value of *M* in that particular subset. In particular, if *M* is fixed and the value *M*=0 is not allowed, then there are no restrictions on *N*, in which case the CCM* mode reduces to the CCM mode.

A.2.1 Input Transformation

This step involves the transformation of the input strings a and m to the strings *AuthData* and *PlainTextData*, to be used by the authentication transformation and the encryption transformation, respectively.

This step involves the following steps, in order:

- 1 Form the octet string representation $L(a)$ of the length $l(a)$ of the octet string a , as follows:
 - a If $l(a)=0$, then $L(a)$ is the empty string.
 - b If $0 < l(a) < 2^{16}-2^8$, then $L(a)$ is the 2-octets encoding of $l(a)$.
 - c If $2^{16}-2^8 \leq l(a) < 2^{32}$, then $L(a)$ is the right-concatenation of the octet 0xff, the octet 0xfe, and the 4-octets encoding of $l(a)$.
 - d If $2^{32} \leq l(a) < 2^{64}$, then $L(a)$ is the right-concatenation of the octet 0xff, the octet 0xff, and the 8-octets encoding of $l(a)$.
- 2 Right-concatenate the octet string $L(a)$ with the octet string a itself. Note that the resulting string contains $l(a)$ and a encoded in a reversible manner.
- 3 Form the padded message *AddAuthData* by right-concatenating the resulting string with the smallest non-negative number of all-zero octets such that the octet string *AddAuthData* has length divisible by 16.
- 4 Form the padded message *PlainTextData* by right-concatenating the octet string m with the smallest non-negative number of all-zero octets such that the octet string *PlainTextData* has length divisible by 16.
- 5 Form the message *AuthData* consisting of the octet strings *AddAuthData* and *PlainTextData*:

$$AuthData = AddAuthData || PlainTextData$$

A.2.2 Authentication Transformation

The data *AuthData* that was established above shall be tagged using the tagging transformation as follows:

- 1 Form the 1-octet *Flags* field consisting of the 1-bit *Reserved* field, the 1-bit *Adata* field, and the 3-bit representations of the integers M and L , as follows:

$$Flags = Reserved || Adata || M || L$$

Here, the 1-bit *Reserved* field is reserved for future expansions and shall be set to '0'. The 1-bit *Adata* field is set to '0' if $l(a)=0$, and set to '1' if $l(a)>0$. The L

field is the 3-bit representation of the integer $L-1$, in most-significant-bit-first order. The M field is the 3-bit representation of the integer $(M-2)/2$ if $M>0$ and of the integer 0 if $M=0$, in most-significant-bit-first order.

- 2 Form the 16-octet B_0 field consisting of the 1-octet *Flags* field defined above, the 15- L octet nonce field N , and the L -octet representation of the length field $l(m)$, as follows:

$$B_0 = \text{Flags} \parallel \text{Nonce } N \parallel l(m)$$

- 3 Parse the message *AuthData* as $B_1 \parallel B_2 \parallel \dots \parallel B_t$, where each message block B_i is a 16-octet string.

The CBC-MAC value X_{t+1} is defined by:

$$X_0 := 0^{128}; X_{i+1} := E(\text{Key}, X_i \oplus B_i) \text{ for } i=0, \dots, t.$$

Here, $E(K, x)$ is the cipher-text that results from encryption of the plaintext x using the established block-cipher encryption function E with key *Key*; the string 0^{128} is the 16-octet all-zero bit string.

The authentication tag T is the result of omitting all but the leftmost M octets of the CBC-MAC value X_{n+1} thus computed.

A.2.3 Encryption Transformation

The data *PlaintextData* that was established in sub-clause A.2.1 (step 4) and the authentication tag T that was established in sub-clause A.2.2 (step 3) shall be encrypted using the encryption transformation as follows:

- 1 Form the 1-octet *Flags* field consisting of two 1-bit *Reserved* fields, and the 3-bit representations of the integers 0 and L , as follows:

$$\text{Flags} = \text{Reserved} \parallel \text{Reserved} \parallel 0 \parallel L$$

Here, the two 1-bit *Reserved* fields are reserved for future expansions and shall be set to '0'. The L field is the 3-bit representation of the integer $L-1$, in most-significant-bit-first order. The '0' field is the 3-bit representation of the integer 0, in most-significant-bit-first order.

Define the 16-octet A_i field consisting of the 1-octet *Flags* field defined above, the 15- L octet nonce field N , and the L -octet representation of the integer i , as follows:

$$A_i = \text{Flags} \parallel \text{Nonce } N \parallel \text{Counter } i, \text{ for } i=0, 1, 2, \dots$$

Note that this definition ensures that all the A_i fields are distinct from the B_0 fields that are actually used, as those have a *Flags* field with a non-zero encoding of M in the positions where all A_i fields have an all-zero encoding of the integer 0 (see sub-clause A.2.2, step 1).

Parse the message *PlaintextData* as $M_1 || \dots || M_t$, where each message block M_i is a 16-octet string.

The ciphertext blocks C_1, \dots, C_t are defined by:

$$C_i := E(\text{Key}, A_i) \oplus M_i \text{ for } i=1, 2, \dots, t$$

The string *Ciphertext* is the result of omitting all but the leftmost $l(m)$ octets of the string $C_1 || \dots || C_t$

Define the 16-octet encryption block S_0 by:

$$S_0 := E(\text{Key}, A_0)$$

- 2 The encrypted authentication tag U is the result of XOR-ing the string consisting of the leftmost M octets of S_0 and the authentication tag T .

Output: If any of the above operations has failed, then output ‘invalid’. Otherwise, output the right-concatenation of the encrypted message *Ciphertext* and the encrypted authentication tag U .

A.3 CCM* Mode Decryption and Authentication Checking Transformation

Input: The CCM* inverse transformation takes as inputs:

- 1 A bit string *Key* of length *keylen* bits to be used as the key. Each entity shall have evidence that access to this key is restricted to the entity itself and its intended key-sharing group member(s).
- 2 A nonce N of $15-L$ octets. Within the scope of any encryption key *Key*, the nonce value shall be unique.
- 3 An octet string c of length $l(c)$ octets, where $0 \leq l(c)-M < 2^{8L}$.
- 4 An octet string a of length $l(a)$ octets, where $0 \leq l(a) < 2^{64}$.

A.3.1 Decryption Transformation

The decryption transformation involves the following steps, in order:

- 1 Parse the message c as $C || U$, where the rightmost string U is an M -octet string. If this operation fails, output ‘invalid’ and stop. U is the purported encrypted authentication tag. Note that the leftmost string C has length $l(c)-M$ octets.
- 2 Form the padded message *CiphertextData* by right-concatenating the string C with the smallest non-negative number of all-zero octets such that the octet string *CiphertextData* has length divisible by 16.
- 3 Use the encryption transformation in sub-clause A.2.3, with the data *CipherTextData* and the tag U as inputs.
- 4 Parse the output string resulting from applying this transformation as $m || T$, where the rightmost string T is an M -octet string. T is the purported authentication tag. Note that the leftmost string m has length $l(c)-M$ octets.

A.3.2 Authentication Checking Transformation

The authentication checking transformation involves the following steps:

- 1 Form the message *AuthData* using the input transformation in sub-clause A.2.1, with the string a and the octet string m that was established in sub-clause A.3.1 (step 4) as inputs.
- 2 Use the authentication transformation in sub-clause A.2.2, with the message *AuthData* as input.
- 3 Compare the output tag *MACTag* resulting from this transformation with the tag T that was established in sub-clause A.3.1 (step 4). If *MACTag*= T , output ‘valid’; otherwise, output ‘invalid’ and stop.

Output: If any of the above verifications has failed, then output ‘invalid’ and reject the octet string m . Otherwise, accept the octet string m and accept one of the key sharing group member(s) as the source of m .

A.4 Restrictions

All implementations shall limit the total amount of data that is encrypted with a single key. The CCM* encryption transformation shall invoke not more than 2^{61} block-cipher encryption function operations in total, both for the CBC-MAC and for the CTR encryption operations.

At CCM* decryption, one shall verify the (truncated) CBC-MAC before releasing any information, such as, *Plaintext*. If the CBC-MAC verification fails, only the fact that the CBC-MAC verification failed shall be exposed; all other information shall be destroyed.

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B

SECURITY BUILDING BLOCKS

This annex specifies the cryptographic primitives and mechanisms that are used to implement the security protocols in this standard.

B.1 Symmetric-Key Cryptographic Building Blocks

The following symmetric-key cryptographic primitives and data elements are defined for use with all security-processing operations specified in this standard.

B.1.1 Block-Cipher

The block-cipher used in this specification shall be the Advanced Encryption Standard AES-128, as specified in FIPS Pub 197. This block-cipher has a key size *keylen* that is equal to the block size, in bits, *i.e.*, *keylen*=128.

B.1.2 Mode of Operation

The block-cipher mode of operation used in this specification shall be the CCM* mode of operation, as specified in sub-clause A.2.3, with the following instantiations:

- 1 Each entity shall use the block-cipher *E* as specified in sub-clause B.1.1.
- 2 All octets shall be represented as specified in the “Conventions and Abbreviations”.
- 3 The parameter *L* shall have the integer value 2.
- 4 The parameter *M* shall have one of the following integer values: 0, 4, 8, or 16.

B.1.3 Cryptographic Hash Function

The cryptographic hash function used in this specification shall be the block-cipher based cryptographic hash function specified in sub-clause B.6, with the following instantiations:

- 1 Each entity shall use the block-cipher *E* as specified in sub-clause B.1.1.
- 2 All integers and octets shall be represented as specified in sub-clause 1.2.1.

The Matyas-Meyer-Oseas hash function (specified in sub-clause B.6) has a message digest size *hashlen* that is equal to the block size, in bits, of the established block-cipher.

B.1.4 Keyed Hash Function for Message Authentication

The keyed hash message authentication code (HMAC) used in this specification shall be HMAC, as specified in the FIPS Pub 198 [B9], with the following instantiations:

- 1 Each entity shall use the cryptographic hash *H* function as specified in sub-clause B.1.3.
- 2 The block size *B* shall have the integer value 16 (this block size specifies the length of the data integrity key, in bytes, that is used by the keyed hash function, *i.e.*, it uses a 128-bit data integrity key).
- 3 The output size *HMAClen* of the HMAC function shall have the same integer value as the message digest parameter *hashlen* as specified in sub-clause B.1.3.

B.1.5 Specialized Keyed Hash Function for Message Authentication

The specialized keyed hash message authentication code used in this specification shall be as specified in sub-clause B.1.4.

B.1.6 Challenge Domain Parameters

The challenge domain parameters used in the specification shall be as specified in sub-clause B.3.1, with the following instantiation: (*minchallengelen*, *maxchallengelen*)=(128,128).

All challenges shall be validated using the challenge validation primitive as specified in sub-clause B.4.

B.2 Key Agreement Schemes

B.2.1 Symmetric-Key Key Agreement Scheme

The symmetric-key key agreement protocols in this standard shall use the full symmetric-key with key confirmation scheme, with the following instantiations:

- 1 Each entity shall use the HMAC-scheme as specified in sub-clause B.1.4.
- 2 Each entity shall use the specialized HMAC-scheme as specified in sub-clause B.1.5.
- 3 Each entity shall use the cryptographic hash function as specified in sub-clause B.1.3.
- 4 The parameter *keydatalen* shall have the same integer value as the key size parameter *keylen* as specified in sub-clause B.1.1.
- 5 The parameter *SharedData* shall be the empty string; parameter *shareddatalen* shall have the integer value 0.
- 6 The optional parameters *Text₁* and *Text₂* as specified in sub-clause B.7.1 and sub-clause B.7.2 shall both be the empty string.
- 7 Each entity shall use the challenge domain parameters as specified in sub-clause B.1.6.
- 8 All octets shall be represented as specified in sub-clause 1.2.1.

B.3 Challenge Domain Parameter Generation and Validation

This section specifies the primitives that shall be used to generate and validate challenge domain parameters.

Challenge domain parameters impose constraints on the length(s) of bit challenges a scheme expects. As such, this establishes a bound on the entropy of challenges and, thereby, on the security of the cryptographic schemes in which these challenges are used. In most schemes, the challenge domain parameters will be such that only challenges of a fixed length will be accepted (e.g., 128-bit challenges). However, one may define the challenge domain parameters such that challenges of varying length might be accepted. Doing so is useful in contexts in which entities that wish to engage in cryptographic schemes might have a bad random number generator onboard. Allowing both entities that engage in a scheme to contribute sufficiently long inputs enables each of them to contribute sufficient entropy to the scheme.

In this standard, challenge domain parameters will be shared by a number of entities using a scheme determined by the standard. The challenge domain parameters may be public; the security of the system does not rely on these parameters being secret.

B.3.1 Challenge Domain Parameter Generation

Challenge domain parameters shall be generated using the following routine.

Input: This routine does not take any input.

Actions: The following actions are taken:

- 1 Choose two nonnegative integers *minchallengelen* and *maxchallengelen*, such that $\text{minchallengelen} \leq \text{maxchallengelen}$.

Output: Challenge domain parameters $D=(\text{minchallengelen}, \text{maxchallengelen})$.

B.3.2 Challenge Domain Parameter Verification

Challenge domain parameters shall be verified using the following routine.

Input: Purported set of challenge domain parameters $D=(\text{minchallengelen}, \text{maxchallengelen})$.

Actions: The following checks are made:

- 1 Check that *minchallengelen* and *maxchallengelen* are non-negative integers.
- 2 Check that $\text{minchallengelen} \leq \text{maxchallengelen}$.

Output: If any of the above verifications has failed, then output ‘invalid’ and reject the challenge domain parameters. Otherwise, output ‘valid’ and accept the challenge domain parameters.

B.4 Challenge Validation Primitive

It is used to check whether a challenge to be used by a scheme in the standard has sufficient length (e.g., messages that are too short are discarded, due to insufficient entropy).

Input: The input of the validation transformation is a valid set of challenge domain parameters $D=(\text{minchallengelen}, \text{maxchallengelen})$, together with the bit string *Challenge*.

Actions: The following actions are taken:

- 1 Compute the bit-length *challengelen* of the bit string *Challenge*.

- 2 Verify that $challenge_{len} \in [minchallenge_{len}, maxchallenge_{len}]$. (That is, verify that the challenge has an appropriate length.)

Output: If the above verification fails, then output ‘invalid’ and reject the challenge. Otherwise, output ‘valid’ and accept the challenge.

B.5 Secret Key Generation (SKG) Primitive

This section specifies the SKG primitive that shall be used by the symmetric-key key agreement schemes specified in this standard.

This primitive derives a shared secret value from a challenge owned by an entity U_1 and a challenge owned by an entity U_2 when all the challenges share the same challenge domain parameters. If the two entities both correctly execute this primitive with corresponding challenges as inputs, the same shared secret value will be produced.

The shared secret value shall be calculated as follows:

Prerequisites: The following are the prerequisites for the use of the SKG primitive:

- 1 Each entity shall be bound to a unique identifier (e.g., distinguished names). All identifiers shall be bit strings of the same length $entlen$ bits. Entity U_1 ’s identifier will be denoted by the bit string U_1 . Entity U_2 ’s identifier will be denoted by the bit string U_2 .
- 2 A specialized MAC scheme shall be chosen, with tagging transformation as specified in Section 5.7.1 of ANSI X9.63-2001 [B7]. The length in bits of the keys used by the specialized MAC scheme is denoted by $mackeylen$.

Input: The SKG primitive takes as input:

- A bit string $MACKey$ of length $mackeylen$ bits to be used as the key of the established specialized MAC scheme.
- A bit string QEU_1 owned by U_1 .
- A bit string QEU_2 owned by U_2 .

Actions: The following actions are taken:

- 1 Form the bit string consisting of U_1 ’s identifier, U_2 ’s identifier, the bit string QEU_1 corresponding to U_1 ’s challenge, and the bit string QEU_2 corresponding to QEU_2 ’s challenge:

$$MacData = U_1 \parallel U_2 \parallel QEU_1 \parallel QEU_2$$

- 2 Calculate the tag *MacTag* for *MacData* under the key *MacKey* using the tagging transformation of the established specialized MAC scheme:

$$MacTag = MAC_{MacKey}(MacData)$$

- 3 If the tagging transformation outputs ‘invalid’, output ‘invalid’ and stop.
- 4 Set $Z = MacTag$.

Output: The bit string *Z* as the shared secret value.

B.6 Block-Cipher-Based Cryptographic Hash Function

This section specifies the Matyas-Meyer-Oseas hash function, a cryptographic hash function based on block-ciphers. We define this hash function for block-ciphers with a key size equal to the block size, such as AES-128, and with a particular choice for the fixed initialization vector *IV* (we take $IV=0$). For a more general definition of the Matyas-Meyer-Oseas hash function, refer to Section 9.4.1 of [B19].

Prerequisites: The following are the prerequisites for the operation of Matyas-Meyer-Oseas hash function:

- 1 A block-cipher encryption function *E* shall have been chosen, with a key size that is equal to the block size. The Matyas-Meyer-Oseas hash function has a message digest size that is equal to the block size of the established encryption function. It operates on bit strings of length less than 2^{2n} , where *n* is the block size, in octets, of the established block-cipher.
- 2 A fixed representation of integers as binary strings or octet strings shall have been chosen.

Input: The input to the Matyas-Meyer-Oseas hash function is as follows:

- 1 A bit string *M* of length *l* bits, where $0 \leq l < 2^{2n}$

Actions: The hash value shall be derived as follows:

- 1 If the message *M* has length less than 2^n bits, pad this message according to the following procedure:
 - a Right-concatenate to the message *M* the binary consisting of the bit ‘1’ followed by *k* ‘0’ bits, where *k* is the smallest non-negative solution to the equation:

$$l + l + k \equiv 7n \pmod{8n} \quad (1)$$

- b Form the padded message M' by right-concatenating to the resulting string the n -bit string that is equal to the binary representation of the integer l .

2 Otherwise pad this message according to the following method:

- a Right concatenate to the message M the binary consisting of the bit '1' followed by k '0' bits, where k is the smallest non-negative solution to the equation:

$$l + 1 + k = 5n \pmod{8n} \quad (2)$$

- b Form the padded message M' by right-concatenating to the resulting string the $2n$ -bit string that is equal to the binary representation of the integer l and right-concatenating to the resulting string the n -bit all-zero bit string.

3 Parse the padded message M' as $M_1 // M_2 // \dots // M_t$ where each message block M_i is an n -octet string.

4 The output $Hash_t$ is defined by

$$Hash_0 = 0^{8n}; Hash_j = E(Hash_{j-1}, M_j) \oplus M_j \text{ for } j=1, \dots, t \quad (3)$$

Here, $E(K, x)$ is the ciphertext that results from encryption of the plaintext x , using the established block-cipher encryption function E with key K ; the string 0^{8n} is the n -octet all-zero bit string.

Output: The bit string $Hash_t$ as the hash value.

Note that the cryptographic hash function operates on bit strength of length less than 2^{2n} bits, where n is the block size (or key size) of the established block cipher, in bytes. For example, the Matyas-Meyer-Oseas hash function with AES-128 operates on bit strings of length less than 2^{32} bits. It is assumed that all hash function calls are on bit strings of length less than 2^{2n} bits. Any scheme attempting to call the hash function on a bit string exceeding 2^{2n} bits shall output 'invalid' and stop.

B.7 Symmetric-Key Authenticated Key Agreement Scheme

This section specifies the full symmetric-key key agreement with key confirmation scheme. A MAC scheme is used to provide key confirmation. Note that all key exchanges and random challenges shall be assumed within data strings in network transmission order.

Figure B.1 illustrates the messaging involved in the use of the full symmetric-key key agreement with key confirmation scheme.

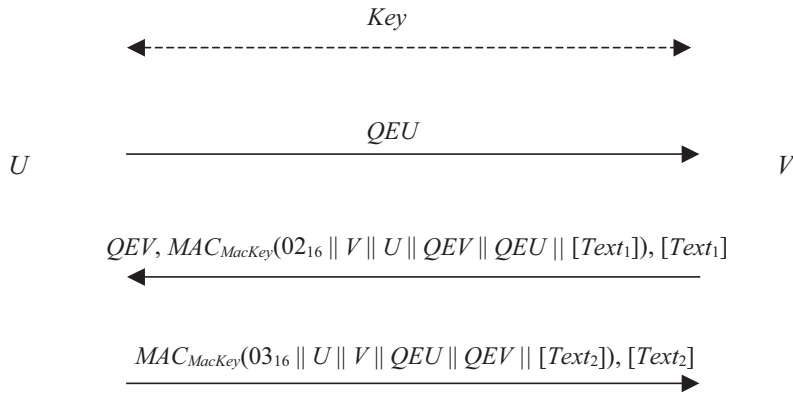


Figure B.1 Symmetric-Key Authenticated Key Agreement Scheme

The scheme is ‘asymmetric’, so two transformations are specified. U uses the transformation specified in sub-clause B.7.1 to agree on keying data with V if U is the protocol’s initiator, and V uses the transformation specified in sub-clause B.7.2 to agree on keying data with U if V is the protocol’s responder.

The essential difference between the role of the initiator and the role of the responder is that the initiator sends the first pass of the exchange.

If U executes the initiator transformation, and V executes the responder transformation with the shared secret keying material as input, then U and V will compute the same keying data.

Prerequisites: The following are the prerequisites for the use of the scheme:

- 1 Each entity has an authentic copy of the system’s challenge domain parameters $D=(minchallenge, maxchallenge)$.
- 2 Each entity shall have access to a bit string *Key* of length *keylen* bits to be used as the key. Each party shall have evidence that access to this key is restricted to the entity itself and the other entity involved in the symmetric-key authenticated key agreement scheme.
- 3 Each entity shall be bound to a unique identifier (e.g., distinguished names). All identifiers shall be bit strings of the same length *entlen* bits. Entity U ’s identifier will be denoted by the bit string U . Entity V ’s identifier will be denoted by the bit string V .
- 4 Each entity shall have decided which MAC scheme to use as specified in Section 5.7 of ANSI X9.63-2001 [B7]. The length in bits of the keys used by the chosen MAC scheme is denoted by *mackeylen*.
- 5 A cryptographic hash function shall have been chosen for use with the key derivation function.

- 6 A specialized MAC scheme shall have been chosen for use with the secret key generation primitive with tagging transformation as specified in Section 5.7.1 of ANSI X9.63-2001 [B7]. The length in bits of the keys used by the specialized MAC scheme is denoted by *keylen*.
- 7 A fixed representation of octets as binary strings shall have been chosen. (e.g., most-significant-bit-first order or least-significant-bit-first order).

B.7.1 Initiator Transformation

U shall execute the following transformation to agree on keying data with *V* if *U* is the protocol's initiator. *U* shall obtain an authentic copy of *V*'s identifier and an authentic copy of the static secret key *Key* shared with *V*.

Input: The input to the initiator transformation is:

- 1 An integer *keydatalen* that is the length in bits of the keying data to be generated.
- 2 (Optional) A bit string *SharedData* of length *shareddatalen* bits that consists of some data shared by *U* and *V*.
- 3 (Optional) A bit string *Text₂* that consists of some additional data to be provided from *U* to *V*.

Ingredients: The initiator transformation employs the challenge generation primitive specified in Section 5.3 of ANSI X9.63-2001 [B7], the challenge validation primitive in sub-clause B.3.2, the SKG primitive in sub-clause B.5, the key derivation function in Section 5.6.3 of ANSI X9.63-2001 [B7], and one of the MAC schemes in Section 5.7 of ANSI X9.63-2001 [B7].

Actions: Keying data shall be derived as follows:

- 1 Use the challenge generation primitive in Section 5.3 of ANSI X9.63-2001 [B7] to generate a challenge *QEU* for the challenge domain parameters *D*. Send *QEU* to *V*.
- 2 Then receive from *V* a challenge *QEV'*, purportedly owned by *V*. If this value is not received, output 'invalid' and stop.
- 3 Verify that *QEV'* is a valid challenge for the challenge domain parameters *D* as specified in sub-clause B.3.2. If the validation primitive rejects the challenge, output 'invalid' and stop.
- 4 Use the SKG primitive given in sub-clause B.5 to derive a shared secret bit string *Z* from the challenges *Q₁*=*QEU* owned by *U* and *Q₂*=*QEV'* owned by *V*, using as key the shared key *Key*. If the SKG primitive outputs 'invalid', output 'invalid' and stop.

5 Use the key derivation function in Section 5.6.3 of ANSI X9.63-2001 [B7] with the established hash function to derive keying data *KKeyData* of length *mackeylen+keydatalen* bits from the shared secret value *Z* and the shared data [*SharedData*].

6 Parse the leftmost *mackeylen* bits of *KKeyData* as a MAC key *MacKey* and the remaining bits as keying data *KeyData*.

7 Form the bit string consisting of the octet 02₁₆, *V*'s identifier, *U*'s identifier, the bit string *QEV*', the bit string *QEU*, and if present *Text*₁:

$$MacData_1 = 02_{16} \parallel V \parallel U \parallel QEV' \parallel QEU \parallel [Text_1]$$

8 Verify that *MacTag*₁' is the tag for *MacData*₁ under the key *MacKey* using the tag checking transformation of the appropriate MAC scheme specified in Section 5.7.2 of ANSI X9.63-2001 [B7]. If the tag checking transformation outputs 'invalid', output 'invalid' and stop.

9 Form the bit string consisting of the octet 03₁₆, *U*'s identifier, *V*'s identifier, the bit string *QEU* corresponding to *U*'s challenge, the bit string *QEV*' corresponding to *V*'s challenge, and optionally a bit string *Text*₂:

$$MacData_2 = 03_{16} \parallel U \parallel V \parallel QEU \parallel QEV' \parallel [Text_2]$$

10 Calculate the tag *MacTag*₂ on *MacData*₂ under the key *MacKey* using the tagging transformation of the appropriate MAC scheme specified in Section 5.7.1 of ANSI X9.63-2001 [B7]:

$$MacTag_2 = MAC_{MacKey}(MacData_2) \quad (4)$$

11 If the tagging transformation outputs 'invalid', output 'invalid' and stop. Send *MacTag*₂ and, if present, *Text*₂ to *V*.

12 Receive from *V* an optional bit string *Text*₁, and a purported tag *MacTag*₁'. If these values are not received, output 'invalid' and stop.

Output: If any of the above verifications has failed, then output 'invalid' and reject the bit strings *KeyData* and *Text*₁. Otherwise, output 'valid', accept the bit string *KeyData* as the keying data of length *keydatalen* bits shared with *V* and accept *V* as the source of the bit string *Text*₁ (if present).

B.7.2 Responder Transformation

V shall execute the following transformation to agree on keying data with *U* if *V* is the protocol's responder. *V* shall obtain an authentic copy of *U*'s identifier and an authentic copy of the static secret key *Key* shared with *U*.

Input: The input to the responder transformation is:

- 1 A challenge *QEU'* purportedly owned by *U*.
- 2 An integer *keydatalen* that is the length in bits of the keying data to be generated.
- 3 (Optional) A bit string *SharedData* of length *shareddatalen* bits that consists of some data shared by *U* and *V*.
- 4 (Optional) A bit string *Text₁* that consists of some additional data to be provided from *V* to *U*.

Ingredients: The responder transformation employs the challenge generation primitive specified in Section 5.3 of ANSI X9.63-2001 [B7], the challenge validation primitive specified in sub-clause B.3.2, the SKG primitive given in sub-clause B.5, the key derivation function in Section 5.6.3 of ANSI X9.63-2001 [B7], and one of the MAC schemes in Section 5.7 of ANSI X9.63-2001 [B7].

Actions: Keying data shall be derived as follows:

- 1 Verify that *QEU'* is a valid challenge for the challenge domain parameters *D* as specified in sub-clause B.3.2. If the validation primitive rejects the challenge, output 'invalid' and stop.
- 2 Use the challenge generation primitive in Section 5.3 of ANSI X9.63-2001 [B7] to generate a challenge *QEV* for the challenge domain parameters *D*. Send to *U* the challenge *QEV*.
- 3 Then receive from *U* an optional bit string *Text₂* and a purported tag *MacTag₂'*. If this data is not received, output 'invalid' and stop.
- 4 Form the bit string consisting of the octet 03₁₆, *U*'s identifier, *V*'s identifier, the bit string *QEU'* corresponding to *U*'s purported challenge, the bit string *QEV* corresponding to *V*'s challenge, and the bit string *Text₂* (if present):

$$MacData2 = 0316 \parallel U \parallel V \parallel QEU' \parallel QEV \parallel [Text2]$$

- 5 Verify that *MacTag₂'* is the valid tag on *MacData₂* under the key *MacKey* using the tag checking transformation of the appropriate MAC scheme specified in Section 5.7 ANSI X9.63-2001 [B7]. If the tag checking transformation outputs 'invalid', output 'invalid' and stop.
- 6 Use the SKG primitive in sub-clause B.5 to derive a shared secret bit string *Z* from the challenges *Q₁=QEU'* owned by *U* and *Q₂=QEV* owned by *V*, using as key the shared key *Key*. If the SKG primitive outputs 'invalid', output 'invalid' and stop.
- 7 Use the key derivation function in Section 5.6.3 of ANSI X9.63-2001 [B7] with the established hash function to derive keying data *KKeyData* of length *mackeylen+keydatalen* bits from the shared secret value *Z* and the shared data [*SharedData*].

8 Parse the leftmost *mackeylen* bits of *KKeyData* as a MAC key *MacKey* and the remaining bits as keying data *KeyData*.

9 Form the bit string consisting of the octet 02₁₆, *V*'s identifier, *U*'s identifier, the bit string *QEV*, the bit string *QEU*', and, optionally, a bit string *Text*₁:

$$MacData1 = 0216 \parallel V \parallel U \parallel QEV \parallel QEU' \parallel [Text1]$$

10 Calculate the tag *MacTag*₁ for *MacData*₁ under the key *MacKey* using the tagging transformation of the appropriate MAC scheme specified in Section 5.7 of ANSI X9.63-2001 [B7]:

$$MacTag_1 = MAC_{MacKey}(MacData_1)$$

If the tagging transformation outputs 'invalid', output 'invalid' and stop. Send to *U*, if present the bit string *Text*₁, and *MacTag*₁.

Output: If any of the above verifications has failed, then output 'invalid' and reject the bit strings *KeyData* and *Text*₂. Otherwise, output 'valid', accept the bit string *KeyData* as the keying data of length *keydatalen* bits shared with *U* and accept *U* as the source of the bit string *Text*₂ (if present).

B.8 Mutual Symmetric-Key Entity Authentication

This section specifies the mutual symmetric-key entity authentication scheme. A MAC scheme is used to provide key confirmation.

Figure B.2 illustrates the messaging involved in the use of mutual symmetric-key entity authentication scheme.

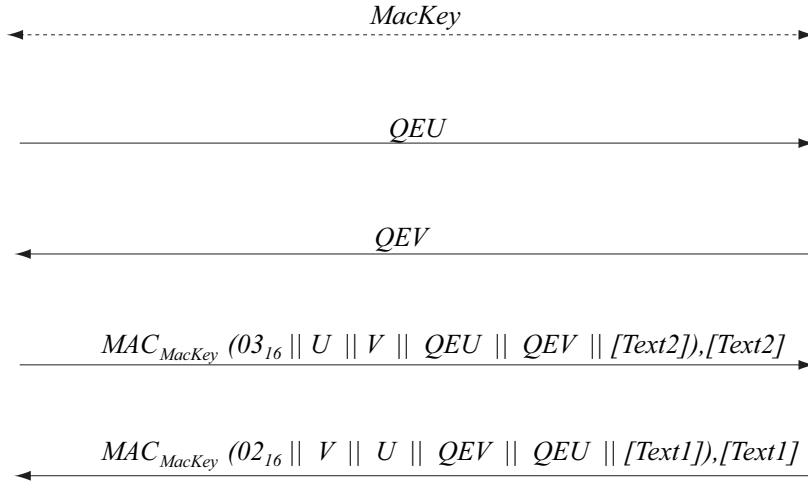


Figure B.2 Mutual Symmetric-Key Entity Authentication Scheme

The scheme is ‘asymmetric’, so two transformations are specified. *U* uses the transformation specified in sub-clause B.8.1 to establish authenticity of, and optionally obtain authenticated data from, *V* by means of sharing a key and communicating cooperatively with *V*. *V* uses the transformation specified in sub-clause B.8.2 to establish authenticity of, and optionally obtain authenticated data from, *U* by means of sharing a key and communicating cooperatively with *U*.

The essential difference between the role of the initiator and the role of the responder is that the initiator sends the first pass of the exchange.

Prerequisites: The following are the prerequisites for the use of the scheme:

- 1** Each entity has an authentic copy of the system’s challenge domain parameters $D=(minchallenge, maxchallenge)$. These parameters shall have been generated using the parameter generation primitive in sub-clause B.3.1. Furthermore, the parameters shall have been validated using the parameter validation primitive in sub-clause B.3.2.
- 2** Each entity shall have access to a bit string *MacKey* of length *mackeylen* bits to be used as the key. Each party shall have evidence that access to this key is restricted to the entity itself and the other entity involved in the mutual entity authentication scheme.
- 3** Each entity shall be bound to a unique identifier (e.g., distinguished names). All identifiers shall be bit strings of the same length *entlen* bits. Entity *U*’s identifier will be denoted by the bit string *U*. Entity *V*’s identifier will be denoted by the bit string *V*.

- 4 Each entity shall have decided which MAC scheme to use as specified in Section 5.7 of ANSI X9.63-2001 [B7]. The length in bits of the keys used by the chosen MAC scheme is denoted by *mackeylen*.
- 5 A fixed representation of octets as binary strings shall have been chosen (e.g., most-significant-bit-first order or least-significant-bit-first order).

B.8.1 Initiator Transformation

U shall execute the following transformation to establish authenticity of, and optionally obtain authenticated data from, *V* by means of sharing a key and communicating cooperatively with *V*. *U* shall obtain an authentic copy of *V*'s identifier and an authentic copy of the secret key *MacKey* shared with *V*.

Input: The input to the initiator transformation is:

- 1 (Optional) A bit string *Text2* that consists of some additional data to be provided from *U* to *V*.

Ingredients: The initiator transformation employs the challenge generation primitive specified in Section 5.3 of ANSI X9.63-2001 [B7], the challenge validation primitive specified in sub-clause B.4, and one of the MAC schemes in Section 5.7 of ANSI X9.63-2001 [B7].

Actions: Entity authentication shall be established as follows:

- 1 Use the challenge generation primitive given in Section 5.3 of ANSI X9.63-2001 [B7] to generate a challenge *QEU* for the challenge domain parameters *D*. Send *QEU* to *V*.
- 2 Then receive from *V* a challenge *QEV'* purportedly owned by *V*. If this value is not received, output 'invalid' and stop.
- 3 Verify that *QEV'* is a valid challenge for the challenge domain parameters *D* as specified in sub-clause B.3.1. If the validation primitive rejects the challenge, output 'invalid' and stop.
- 4 Form the bit string consisting of the octet 03_{16} , *U*'s identifier, *V*'s identifier, the bit string *QEU* corresponding to *U*'s challenge, the bit string *QEV'* corresponding to *V*'s purported challenge, and optionally a bit string *Text2*:

$$MacData2 = 03_{16} || U || V || QEU || QEV' || [Text2].$$

- 5 Calculate the tag *MacTag2* on *MacData2* under the key *MacKey* using the tagging transformation of the appropriate MAC scheme specified in Section 5.7.1 of ANSI X9.63-2001 [B7]:

$$MacTag2 = MAC_{MacKey}(MacData2).$$

If the tagging transformation outputs ‘invalid’, output ‘invalid’ and stop. Send *MacTag2* and, if present, bit string *Text2* to *V*.

- 6 Receive from *V* an optional bit string *Text1*, and a purported tag *MacTag1'*. If these values are not received, output ‘invalid’ and stop.
- 7 Form the bit string consisting of the octet 02_{16} , *V*’s identifier, *U*’s identifier, the bit string *QEV'* corresponding to *V*’s purported challenge, the bit string *QEU* corresponding to *U*’s challenge, and if present *Text1*:

$$MacData1 = 02_{16} || V || U || QEV' || QEU || [Text1].$$

- 8 Verify that *MacTag1'* is the tag for *MacData1* under the key *MacKey* using the tag checking transformation of the appropriate MAC scheme specified in Section 5.7.2 of ANSI X9.63-2001 [B7]. If the tag checking transformation outputs ‘invalid’, output ‘invalid’ and stop.

Output: If any of the above verifications has failed, then output ‘invalid’ and reject the authenticity of *V* and reject the entity authentication from *V*. Otherwise, output ‘valid’, accept the authenticity of *V* and accept the entity authentication from *V* of the authenticated bit string *Text1* (if present).

B.8.2 Responder Transformation

V shall execute the following transformation to establish authenticity, of and optionally obtain authenticated data from, *U* by means of sharing a key and communicating cooperatively with *U*. *V* shall obtain an authentic copy of *U*’s identifier and an authentic copy of the secret key *MacKey* shared with *U*.

Input: The input to the responder transformation is:

- 1 A challenge *QEU'* purportedly owned by *U*.
- 2 (Optional) A bit string *Text1* that consists of some additional data to be provided from *V* to *U*.

Ingredients: The responder transformation employs the challenge generation primitive specified in Section 5.3 of ANSI X9.63-2001 [B7], the challenge validation primitive specified in sub-clause B.4, and one of the MAC schemes in Section 5.7 of ANSI X9.63-2001 [B7].

Actions: Entity authentication shall be established as follows:

- 1 Verify that *QEU'* is a valid challenge for the challenge domain parameters *D* as specified in sub-clause B.3.1. If the validation primitive rejects the challenge, output ‘invalid’ and stop.

2 Use the challenge generation primitive in Section 5.3 of ANSI X9.63-2001 [B7] to generate a challenge QEV for the challenge domain parameters D . Send QEV to U .

3 Then receive from U an optional bit string $Text2$ and a purported tag $MacTag2'$. If this data is not received, output 'invalid' and stop.

4 Form the bit string consisting of the octet 03_{16} , U 's identifier, V 's identifier, the bit string QEU' corresponding to U 's purported challenge, the bit string QEV corresponding to V 's challenge, and the bit string $Text2$ (if present):

$$MacData2 = 03_{16} || U || V || QEU' || QEV || [Text2]$$

5 Calculate the tag $MacTag2$ for $MacData2$ under the key $MacKey$ using the tagging transformation of the appropriate MAC scheme specified in Section 5.7.1 of ANSI X9.63-2001 [B7]:

$$MacTag2 = MAC_{MacKey}(MacData2).$$

If the tagging transformation outputs 'invalid', output 'invalid' and stop.

6 Verify that $MacTag2'$ is the valid tag on $MacData2$ under the key $MacKey$ using the tag checking transformation of the appropriate MAC scheme specified in Section 5.7.2 of ANSI X9.63-2001 [B7]. If the tag checking transformation outputs 'invalid', output 'invalid' and stop.

7 Form the bit string consisting of the octet 02_{16} , V 's identifier, U 's identifier, the bit string QEV corresponding to V 's challenge, the bit string QEU' corresponding to U 's purported challenge and optionally a bit string $Text1$:

$$MacData1 = 02_{16} || V || U || QEV || QEU' || [Text1].$$

8 Calculate the tag $MacTag1$ for $MacData1$ under the key $MacKey$ using the tagging transformation of the appropriate MAC scheme specified in Section 5.7.1 of ANSI X9.63-2001 [B7]:

$$MacTag1 = MAC_{MacKey}(MacData1).$$

If the tagging transformation outputs 'invalid', output 'invalid' and stop. Send $MacTag1$ and, if present, bit string $Text1$ to U .

Output: If any of the above verifications has failed, then output 'invalid' and reject the authenticity of U and reject the entity authentication from U . Otherwise, output 'valid', accept the authenticity of U and accept the entity authentication from U of the authenticated bit string $Text2$ (if present).

A N N E X

C

TEST VECTORS FOR CRYPTOGRAPHIC BUILDING BLOCKS

This annex provides sample test vectors for the ZigBee community, aimed at with the intent of assisting in building interoperable security implementations. The sample test vectors are provided as is, pending independent validation.

C.1 Data Conversions

For test vectors, see Appendix J1 of ANSI X9.63-2001 [B7].

C.2 AES Block Cipher

This annex provides sample test vectors for the block-cipher specified in sub-clause B.1.1.

For test vectors, see FIPS Pub 197 [B8].

C.3 CCM* Mode Encryption and Authentication Transformation

This annex provides sample test vectors for the mode of operation as specified in sub-clause B.1.2.

Prerequisites: The following prerequisites are established for the operation of the mode of operation:

- 1 The parameter M shall have the integer value 8.

Input: The inputs to the mode of operation are:

- 1 The key *Key* of size *keylen*=128 bits to be used:

Key = C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB CC CD CE CF

- 2 The nonce *N* of 15-*L*=13 octets to be used:

Nonce = A0 A1 A2 A3 A4 A5 A6 A7 || 03 02 01 00 || 06

- 3 The octet string *m* of length *l(m)*=23 octets to be used:

m = 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18 19 1A 1B 1C 1D 1E

- 4 The octet string *a* of length *l(a)*=8 octets to be used:

a = 00 01 02 03 04 05 06 07

C.3.1 Input Transformation

This step involves the transformation of the input strings *a* and *m* to the strings *AuthData* and *PlainTextData*, to be used by the authentication transformation and the encryption transformation, respectively.

- 1 Form the octet string representation *L(a)* of the length *l(a)* of the octet string *a*:

L(a) = 00 08

- 2 Right-concatenate the octet string *L(a)* and the octet string *a* itself:

L(a) || *a* = 00 08 || 00 01 02 03 04 05 06 07

- 3 Form the padded message *AddAuthData* by right-concatenating the resulting string with the smallest non-negative number of all-zero octets such that the octet string *AddAuthData* has length divisible by 16:

AddAuthData = 00 08 || 00 01 02 03 04 05 06 07 || 00 00 00 00 00 00

- 4 Form the padded message *PlainTextData* by right-concatenating the octet string *m* with the smallest non-negative number of all-zero octets such that the octet string *PlainTextData* has length divisible by 16:

PlainTextData = 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 ||
18 19 1A 1B 1C 1D 1E || 00 00 00 00 00 00 00 00

- 5 Form the message *AuthData* consisting of the octet strings *AddAuthData* and *PlainTextData*:

AuthData = 00 08 00 01 02 03 04 05 06 07 00 00 00 00 00 00 //
08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17
18 19 1A 1B 1C 1D 1E 00 00 00 00 00 00 00 00 00

C.3.2 Authentication Transformation

The data *AuthData* that was established above shall be tagged using the following tagging transformation:

- 1 Form the 1-octet *Flags* field as follows:

Flags = 59

- 2 Form the 16-octet *B*₀ field as follows:

*B*₀ = 59 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 17

- 3 Parse the message *AuthData* as *B*₁ || *B*₂ || *B*₃, where each message block *B*_{*i*} is a 16-octet string.

- 4 The CBC-MAC value *X*₄ is calculated as follows:

i	<i>B</i> _{<i>i</i>}	<i>X</i> _{<i>i</i>}
0	59 A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 00 17	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
1	00 08 00 01 02 03 04 05 06 07 00 00 00 00 00 00	F7 74 D1 6E A7 2D C0 B3 E4 5E 36 CA 8F 24 3B 1A
2	08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17	90 2E 72 58 AE 5A 4B 5D 85 7A 25 19 F3 C7 3A B3
3	18 19 1A 1B 1C 1D 1E 00 00 00 00 00 00 00 00 00	5A B2 C8 6E 3E DA 23 D2 7C 49 7D DF 49 BB B4 09
4	æ	B9 D7 89 67 04 BC FA 20 B2 10 36 74 45 F9 83 D6

The authentication tag *T* is the result of omitting all but the leftmost *M*=8 octets of the CBC-MAC value *X*₄:

T = B9 D7 89 67 04 BC FA 20

C.3.3 Encryption Transformation

The data *PlaintextData* shall be encrypted using the following encryption transformation:

- 1 Form the 1-octet *Flags* field as follows:

Flags = 01

2 Define the 16-octet A_i field as follows

i	A_i
0	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 00
1	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 01
2	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 02

3 Parse the message *PlaintextData* as $M_1 || M_2$, where each message block M_i is a 16-octet string.

4 The ciphertext blocks C_1, C_2 are computed as follows:

i	$AES(Key, A_i)$	$C_i = AES(Key, A_i) \oplus M_i$
1	12 5C A9 61 B7 61 6F 02 16 7A 21 66 70 89 F9 07	1A 55 A3 6A BB 6C 61 0D 06 6B 33 75 64 9C EF 10
2	CC 7F 54 D1 C4 49 B6 35 46 21 46 03 AA C6 2A 17	D4 66 4E CA D8 54 A8 35 46 21 46 03 AA C6 2A 17

5 The string *Ciphertext* is the result of omitting all but the leftmost $l(m)=23$ octets of the string $C_1 || C_2$:

CipherText = 1A 55 A3 6A BB 6C 61 0D 06 6B 33 75 64 9C EF 10 || D4 66 4E CA D8 54 A8

6 Define the 16-octet encryption block S_0 by:

$S_0 = E(Key, A_0) = B3 5E D5 A6 DC 43 6E 49 D6 17 2F 54 77 EB B4 39$

7 The encrypted authentication tag U is the result of XOR-ing the string consisting of the leftmost $M=8$ octets of S_0 and the authentication tag T :

$U = 0A 89 5C C1 D8 FF 94 69$

Output: the right-concatenation c of the encrypted message *Ciphertext* and the encrypted authentication tag U :

$c = 1A 55 A3 6A BB 6C 61 0D 06 6B 33 75 64 9C EF 10 || D4 66 4E CA D8 54 A8 || 0A 89 5C C1 D8 FF 94 69$

C.4 CCM* Mode Decryption and Authentication Checking Transformation

This annex provides sample test vectors for the inverse of the mode of operation as specified in sub-clause B.1.2.

Prerequisites: The following prerequisites are established for the operation of the mode of operation:

- 1 The parameter M shall have the integer value 8.

Input: The inputs to the inverse mode of operation are:

- 1 The key Key of size $keylen=128$ bits to be used:

$Key = C0\ C1\ C2\ C3\ C4\ C5\ C6\ C7\ C8\ C9\ CA\ CB\ CC\ CD\ CE\ CF$

- 2 The nonce N of $15-L=13$ octets to be used:

$Nonce = A0\ A1\ A2\ A3\ A4\ A5\ A6\ A7\ ||\ 03\ 02\ 01\ 00\ ||\ 06$

- 3 The octet string c of length $l(c)=31$ octets to be used:

$c = 1A\ 55\ A3\ 6A\ BB\ 6C\ 61\ 0D\ 06\ 6B\ 33\ 75\ 64\ 9C\ EF\ 10\ ||\ D4\ 66\ 4E\ CA\ D8\ 54\ A8\ ||\ 0A\ 89\ 5C\ C1\ D8\ FF\ 94\ 69$

- 4 The octet string a of length $l(a)=8$ octets to be used:

$a = 00\ 01\ 02\ 03\ 04\ 05\ 06\ 07$

C.4.1 Decryption Transformation

The decryption transformation involves the following steps, in order:

- 1 Parse the message c as $C || U$, where the rightmost string U is an M -octet string:

$C = 1A\ 55\ A3\ 6A\ BB\ 6C\ 61\ 0D\ 06\ 6B\ 33\ 75\ 64\ 9C\ EF\ 10\ ||\ D4\ 66\ 4E\ CA\ D8\ 54\ A8;$

$U = 0A\ 89\ 5C\ C1\ D8\ FF\ 94\ 69$

- 2 Form the padded message $CiphertextData$ by right-concatenating the string C with the smallest non-negative number of all-zero octets such that the octet string $CiphertextData$ has length divisible by 16.

$CipherTextData = 1A\ 55\ A3\ 6A\ BB\ 6C\ 61\ 0D\ 06\ 6B\ 33\ 75\ 64\ 9C\ EF\ 10\ ||\ D4\ 66\ 4E\ CA\ D8\ 54\ A8\ ||\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00$

3 Form the 1-octet *Flags* field as follows:

$Flags = 01$

4 Define the 16-octet A_i field as follows:

i	A_i
0	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 00
1	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 01
2	01 || A0 A1 A2 A3 A4 A5 A6 A7 03 02 01 00 06 || 00 02

5 Parse the message *CiphertextData* as $C_1 || C_2$, where each message block C_i is a 16-octet string.

6 The ciphertext blocks P_1, P_2 are computed as follows:

i	$AES(Key, A_i)$	$P_i = AES(Key, A_i) \oplus C_i$
1	12 5C A9 61 B7 61 6F 02 16 7A 21 66 70 89 F9 07	08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17
2	CC 7F 54 D1 C4 49 B6 35 46 21 46 03 AA C6 2A 17	18 19 1A 1B 1C 1D 1E 00 00 00 00 00 00 00 00

7 The octet string m is the result of omitting all but the leftmost $l(m)=23$ octets of the string $P_1 || P_2$:

$m = 08\ 09\ 0A\ 0B\ 0C\ 0D\ 0E\ 0F\ 10\ 11\ 12\ 13\ 14\ 15\ 16\ 17\ ||\ 18\ 19\ 1A\ 1B\ 1C\ 1D\ 1E$

8 Define the 16-octet encryption block S_0 by

$S_0 = E(Key, A_0) = B3\ 5E\ D5\ A6\ DC\ 43\ 6E\ 49\ D6\ 17\ 2F\ 54\ 77\ EB\ B4\ 39$

9 The purported authentication tag T is the result of XOR-ing the string consisting of the leftmost $M=8$ octets of S_0 and the octet string U :

$T = B9\ D7\ 89\ 67\ 04\ BC\ FA\ 20$

C.4.2 Authentication Checking Transformation

The authentication checking transformation involves the following steps:

1 Form the message *AuthData* using the input transformation in sub-clause C.3.1, with the string a as inputs and the octet string m that was established in sub-clause C.4.1 (step 7):

AuthData = 08 00 01 02 03 04 05 06 07 00 00 00 00 00 00 00 ||
08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17
18 19 1A 1B 1C 1D 1E 00 00 00 00 00 00 00 00 00

- 2 Use the authentication transformation in sub-clause C.3.2, with the message *AuthData* to compute the authentication tag *MACTag* as input:

MACTag = B9 D7 89 67 04 BC FA 20

- 3 Compare the output tag *MACTag* resulting from this transformation with the tag *T* that was established in sub-clause C.4.1 (step 9):
T = B9 D7 89 67 04 BC FA 20 = *MACTag*

Output: Since *MACTag*=*T*, output ‘valid’ and accept the octet string *m* and accept one of the key sharing group member(s) as the source of *m*.

C.5 Cryptographic Hash Function

This annex provides sample test vectors for the cryptographic hash function specified in clause C.5.

C.5.1 Test Vector Set 1

Input: The input to the cryptographic hash function is as follows:

- 1 The bit string *M* of length *l*=8 bits to be used:

M=C0

Actions: The hash value shall be derived as follows:

- 1 Pad the message *M* by right-concatenating to *M* the bit ‘1’ followed by the smallest non-negative number of ‘0’ bits, such that the resulting string has length 14 (mod 16) octets:

C0 || 80 00 00 00 00 00 00 00 00 00 00 00 00 00

- 2 Form the padded message *M'* by right-concatenating to the resulting string the 16-bit string that is equal to the binary representation of the integer *l*:

M' = C0 || 80 00 00 00 00 00 00 00 00 00 00 00 00 || 00 08

- 3 Parse the padded message *M'* as *M*₁, where each message block *M*_{*i*} is a 16-octet string.

4 The hash value $Hash_1$ is computed as follows:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	æ
1	AE 3A 10 2A 28 D4 3E E0 D4 A0 9E 22 78 8B 20 6C	C0 80 00 00 00 00 00 00 00 00 00 00 00 00 00 08

Output: the 16-octet string $Hash = Hash_1 =$ AE 3A 10 2A 28 D4 3E E0 D4 A0 9E 22 78 8B 20 6C.

C.5.2 Test Vector Set 2

Input: The input to the cryptographic hash function is as follows:

1 The bit string M of length $l=128$ bits to be used:

$M=C0\ C1\ C2\ C3\ C4\ C5\ C6\ C7\ C8\ C9\ CA\ CB\ CC\ CD\ CE\ CF$

Actions: The hash value shall be derived as follows:

1 Pad the message M by right-concatenating to M the bit ‘1’ followed by the smallest non-negative number of ‘0’ bits, such that the resulting string has length 14 (mod 16) octets:

$C0\ C1\ C2\ C3\ C4\ C5\ C6\ C7\ C8\ C9\ CA\ CB\ CC\ CD\ CE\ CF\ ||$
 $80\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00$

2 Form the padded message M' by right-concatenating to the resulting string the 16-bit string that is equal to the binary representation of the integer l :

$M' = C0\ C1\ C2\ C3\ C4\ C5\ C6\ C7\ C8\ C9\ CA\ CB\ CC\ CD\ CE\ CF\ ||$
 $80\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ ||\ 00\ 80$

3 Parse the padded message M' as $M_1\ ||\ M_2$, where each message block M_i is a 16-octet string.

4 The hash value $Hash_2$ is computed as follows:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	æ
1	84 EE 75 E5 4F 9A 52 0F 0B 30 9C 35 29 1F 83 4F	C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB CC CD CE CF
2	A7 97 7E 88 BC 0B 61 E8 21 08 27 10 9A 22 8F 2D	80 00 00 00 00 00 00 00 00 00 00 00 00 00 00 08

Output: the 16-octet string $Hash = Hash_2 =$ A7 97 7E 88 BC 0B 61 E8 21 08 27 10 9A 22 8F 2D.

C.5.3 Test Vector Set 3

Input: The input to the cryptographic hash function is as follows:

- 1 The bit string M of length $l = 65528$ bits to be used.
- 2 8191 bytes (sequence of 0, 1, 2, ... 255, 0, 1, 2, ...)
- 3 This test vector is beneath the threshold of a 216 bit string so the first padding method described in clause B.6 is utilized.

Actions: The hash value shall be derived as follows:

- 1 Pad the message by right-concatenating to M the bit 1 followed by the smallest non-negative number of '0' bits, such that the resulting string has length $14 \pmod{16}$ octets:

```
00 01 02 03 04 ... FB FC FD FE || 80 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00
```

- 2** Form the padded message M' by right-concatenating to the resulting string the 16-bit string that is equal to the binary representation of the integer l :

```
00 01 02 03 04 ... FB FC FD FE || 80 00 00 00 00 00 00 00 00 00 00 00 00 00
00 || FF F8
```

- 3 Parse the padded message M' as M_I , where each message block M_i is a 16-octet string.
- 4 The hash value $Hash_I$ is computed as follows using 16-byte hash block operations:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	-
1	7A CB 0D DA B8 D3 EA 7B 97 9E 4C 6D 1A EB AC 8D	00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
...
i - 1	C3 22 D1 D3 9D 10 86 43 82 06 BD EB 26 41 66 1C	F0 F1 F2 F3 F4 F5 F6 F7 F8 F9 FA FB FC FD FE 80
i	24 EC 2F E7 5B BF FC B3 47 89 BC 06 10 E7 F1 65	00 00 00 00 00 00 00 00 00 00 00 00 00 00 FF F8

C.5.4 Test Vector 4

Input: The input to the cryptographic hash function is as follows:

- 1 The bit string M of length $l = 65536$ bits to be used.
- 2 8192 bytes (sequence of 0, 1, 2, ... 255, 0, 1, 2, ...)

3 This test vector is above the threshold of a 216 bit string so the second padding method described in clause B.6 is utilized.

Actions: The hash value shall be derived as follows.

1 Pad the message by right-concatenating to M the bit 1 followed by the smallest non-negative number of '0' bits, such that the resulting string has length 10 (mod 16) octets:

00 01 02 03 04 ... FB FC FD FE FF || 80 00 00 00 00 00 00 00 00 00

2 Form the padded message M' by right-concatenating to the resulting string the 32-bit string that is equal to the binary representation of the integer 1:

00 01 02 03 04 ... FB FC FD FE FF || 80 00 00 00 00 00 00 00 00 00 || 00 01 00 00

3 Concatenate a 16-bit string of zeros for the padding normally used by the first padding method described in clause B.6.

00 01 02 03 04 ... FB FC FD FE FF || 80 00 00 00 00 00 00 00 00 00 || 00 01 00 00 || 00 00

4 Parse the padded message M' as M_i , where each message block M_i is a 16-octet string.

5 The hash value $Hash_l$ is computed as follows using 16-byte hash block operations:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	-
1	7A CB 0D DA B8 D3 EA 7B 97 9E 4C 6D 1A EB AC 8D	00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
...
i - 1	4E 55 0D CE 34 31 42 96 41 BA D0 C7 BC 44 34 67	F0 F1 F2 F3 F4 F5 F6 F7 F8 F9 FA FB FC FD FE FF
i	24 EC 2F E7 5B BF FC B3 47 89 BC 06 10 E7 F1 65	80 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00

C.5.5 Test Vector 5

Input: The input to the cryptographic hash function is as follows:

- 1 The bit string M of length $l = 65608$ bits to be used.
- 2 8201 bytes (sequence of 0, 1, 2, ... 255, 0, 1, 2, ...)
- 3 This test vector is above the threshold of a 216 bit string so the second padding method described in clause B.6 is utilized.

Actions: The hash value shall be derived as follows.

- 1 Pad the message by right-concatenating to M the bit 1 followed by the smallest non-negative number of '0' bits, such that the resulting string has length $10 \pmod{16}$ octets:

00 01 02 03 04 ... 04 05 06 07 08 || 80

- 2 Form the padded message M' by right-concatenating to the resulting string the 32-bit string that is equal to the binary representation of the integer l :

00 01 02 03 04 ... 04 05 06 07 08 || 80 || 00 01 00 48

- 3 Concatenate a 16-bit string of zeros for the padding normally used by the first padding method described in clause B.6.

00 01 02 03 04 ... 04 05 06 07 08 || 80 || 00 01 00 48 || 00 00

- 4 Parse the padded message M' as M_l , where each message block M_i is a 16-octet string.

- 5 The hash value $Hash_l$ is computed as follows using 16-byte hash block operations:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	-
1	7A CB 0D DA B8 D3 EA 7B 97 9E 4C 6D 1A EB AC 8D	00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
...
i - 1	4E 55 0D CE 34 31 42 96 41 BA D0 C7 BC 44 34 67	F0 F1 F2 F3 F4 F5 F6 F7 F8 F9 FA FB FC FD FE FF
i	72 C9 B1 5E 17 8A A8 43 E4 A1 6C 58 E3 36 43 A3	00 01 02 03 04 05 06 07 08 80 00 01 00 48 00 00

C.5.6 Test Vector 6

Input: The input to the cryptographic hash function is as follows:

- 1 The bit string M of length $l = 65616$ bits to be used.
- 2 8202 bytes (sequence of 0, 1, 2, ... 255, 0, 1, 2, ...)
- 3 This test vector is above the threshold of a 216 bit string so the second padding method described in clause B.6 is utilized.

Actions: The hash value shall be derived as follows.

- 1

Pad the message by right-concatenating to M the bit 1 followed by the smallest non-negative number of '0' bits, such that the resulting string has length 10 (mod 16) octets:

00 01 02 03 04 ... 05 06 07 08 09 || 80 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
- 2

Form the padded message M' by right-concatenating to the resulting string the 32-bit string that is equal to the binary representation of the integer l :

00 01 02 03 04 ... 05 06 07 08 09 || 80 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 || 00 01 00 50
- 3

Concatenate a 16-bit string of zeros for the padding normally used by the first padding method described in clause B.6.

00 01 02 03 04 ... 05 06 07 08 09 || 80 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 || 00 01 00 50 || 00 00
- 4

Parse the padded message M' as M_l , where each message block M_i is a 16-octet string.
- 5

The hash value $Hash_l$ is computed as follows using 16-byte hash block operations:

i	Hash _i	M _i
0	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00	-
1	7A CB 0D DA B8 D3 EA 7B 97 9E 4C 6D 1A EB AC 8D	00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
...
i - 1	CC C1 F8 A3 D5 6A 93 20 41 08 10 2B 46 25 0D A7	00 01 02 03 04 05 06 07 08 09 80 00 00 00 00 00
i	BC 98 28 D5 9B 2A A3 23 DA F2 0B E5 F2 E6 65 11	00 00 00 00 00 00 00 00 00 00 00 01 00 50 00 00

C.6 Keyed Hash Function for Message Authentication

This annex provides sample test vectors for the keyed hash function for message authentication as specified in clause C.6.

C.6.1 Test Vector Set 1

Input: The input to the keyed hash function is as follows:

- 1 The key *Key* of size *keylen*=128 bits to be used:

Key = 40 41 42 43 44 45 46 47 48 49 4A 4B 4C 4D 4E 4F

- 2 The bit string *M* of length *l*=8 bits to be used:

M=C0

Actions: The keyed hash value shall be derived as follows:

- 1 Create the 16-octet string *ipad* (inner pad) as follows:

ipad = 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36

- 2 Form the inner key *Key*₁ by XOR-ing the bit string *Key* and the octet string *ipad*:

*Key*₁ = *Key* ⊕ *ipad* = 76 77 74 75 72 73 70 71 7E 7F 7C 7D 7A 7B 78 79

- 3 Form the padded message *M*₁ by right-concatenating the bit string *Key*₁ with the bit string *M*:

*M*₁ = *Key*₁ || *M* = 76 77 74 75 72 73 70 71 7E 7F 7C 7D 7A 7B 78 79 || C0

- 4 Compute the hash value *Hash*₁ of the bit string *M*₁:

*Hash*₁ = 3C 3D 53 75 29 A7 A9 A0 3F 66 9D CD 88 6C B5 2C

- 5 Create the 16-octet string *opad* (outer pad) as follows:

opad = 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C

- 6 Form the outer key *Key*₂ by XOR-ing the bit string *Key* and the octet string *opad*:

*Key*₂ = *Key* ⊕ *opad* = 1C 1D 1E 1F 18 19 1A 1B 14 15 16 17 10 11 12 13

- 7 Form the padded message *M*₂ by right-concatenating the bit string *Key*₂ with the bit string *Hash*₁:

*M*₂ = *Key*₂ || *Hash*₁ = 1C 1D 1E 1F 18 19 1A 1B 14 15 16 17 10 11 12 13 ||
3C 3D 53 75 29 A7 A9 A0 3F 66 9D CD 88 6C B5 2C

- 8 Compute the hash value *Hash*₂ of the bit string *M*₂:

*Hash*₂ = 45 12 80 7B F9 4C B3 40 0F 0E 2C 25 FB 76 E9 99

Output: the 16-octet string *HMAC* = *Hash*₂ = 45 12 80 7B F9 4C B3 40 0F 0E 2C 25 FB 76 E9 99

C.6.2 Test Vector Set 2

Input: The input to the keyed hash function is as follows:

- 1 The key *Key* of size *keylen*=256 bits to be used:

Key = 40 41 42 43 44 45 46 47 48 49 4A 4B 4C 4D 4E 4F ||
50 51 52 53 54 55 56 57 58 59 5A 5B 5C 5D 5E 5F

- 2 The bit string *M* of length *l*=128 bits to be used:

M = C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB CC CD CE CF

Actions: The keyed hash value shall be derived as follows:

- 1 Compute the hash value *Key*₀ of the bit string *Key*:

*Key*₀ = 22 F4 0C BE 15 66 AC CF EB 77 77 E1 C4 A9 BB 43

- 2 Create the 16-octet string *ipad* (inner pad) as follows:

ipad = 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36 36

- 3 Form the inner key *Key*₁ by XOR-ing the bit key *Key*₀ and the octet string *ipad*:

*Key*₁ = *Key*₀ ⊕ *ipad* = 14 C2 3A 88 23 50 9A F9 DD 41 41 D7 F2 9F 8D 75

- 4 Form the padded message *M*₁ by right-concatenating the bit string *Key*₁ with the bit string *M*:

*M*₁ = *Key*₁ || *M* = 14 C2 3A 88 23 50 9A F9 DD 41 41 D7 F2 9F 8D 75 ||
C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB CC CD CE CF

- 5 Compute the hash value *Hash*₁ of the bit string *M*₁:

*Hash*₁ = 42 65 BE 29 74 55 8C A2 7B 77 85 AC 73 F2 22 10

- 6 Create the 16-octet string *opad* (outer pad) as follows:

opad = 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C 5C

- 7 Form the outer key *Key*₂ by XOR-ing the bit string *Key*₀ and the octet string *opad*:

*Key*₂ = *Key*₀ ⊕ *opad* = 7E A8 50 E2 49 3A F0 93 B7 2B 2B BD 98 F5 E7 1F

- 8 Form the padded message *M*₂ by right-concatenating the bit string *Key*₂ with the bit string *Hash*₁:

*M*₂ = *Key*₂ || *Hash*₁ = 7E A8 50 E2 49 3A F0 93 B7 2B 2B BD 98 F5 E7 1F ||
42 65 BE 29 74 55 8C A2 7B 77 85 AC 73 F2 22 10

9 Compute the hash value $Hash_2$ of the bit string M_2 :

$Hash_2 = A3\ B0\ 07\ 99\ 84\ BF\ 15\ 57\ F7\ 4A\ 0D\ 63\ 87\ E0\ A1\ 1A$

Output: the 16-octet string $HMAC = Hash_2 = A3\ B0\ 07\ 99\ 84\ BF\ 15\ 57\ F7\ 4A\ 0D\ 63\ 87\ E0\ A1\ 1A$

C.6.3 Specialized Keyed Hash Function for Message Authentication

This annex provides sample test vectors for the specialized keyed hash function for message authentication as specified in clause C.6.3.

For test vectors, see clause C.6.

C.6.4 Symmetric-Key Key Agreement Scheme and Entity Authentication Scheme

This text provides details of the intermediate steps and the results for the SKKE and EA algorithms utilized by ZigBee. It is intended to help those who wish to implement the algorithms by verifying their results.

It is expected that the MAC functionality (to Hash data using a key) has already been verified.

C.6.4.1 Endian Issues

The following are the ways in which the data elements are interpreted with the SKKE / EA messages:

- Initiator and Responder IEEE Addresses are sent over-the-air as Little Endian, but they are concatenated in the bit strings also as Big Endian values.
- Keys are interpreted over-the-air as Little Endian, and used as Little Endian values.
- Initiator and Responder Challenges are interpreted over-the-air as Little Endian. They are concatenated in the bit strings also as Little Endian values.
- MacTag data is interpreted as Little Endian and sent over-the-air in the same way as it is derived via the algorithms.
- Frame Counters are sent over-the-air as Little Endian, but are concatenated in the bit strings as Big Endian.

Legend:

(<) Indicates the number is little-endian, e.g. (<)1234 displayed in big-endian form is 0x3412.

(>) Indicates the number is big-endian.

C.6.4.2 SKKE Initiator Transform

Term	Description
Key	Shared key (i.e. Trust Center Master)
MacKey	A key created during generation of keying data
U	Initiator's unique ID (EUI64 Address)
V	Responder's unique ID (EUI64 Address)
QEU	Initiator challenge (16 byte random number)
QEV	Responder challenge (16 byte random number)
MAC	Our HMAC Function
Text1	Optional bit string. Not used in SKKE.
Text2	""
SharedData	Optional data shared between initiator and responder. An empty string for SKKE / EA.

Note: '|' in this pseudo-code means concatenation

- 1 Responder's IEEE (V) must be known ahead of time
- 2 Generate Initiator Challenge QEU
- 3 Send Initiator Challenge and Initiator IEEE to Responder (SKKE-1)
- 4 Receive Responder Challenge, QEV (SKKE-2)
- 5 Calculate shared secret bit string Z.

a MacData1 = U || V || QEU || QEV

b MacTag1 = MAC(MacData1, Key)

c Z = MacTag1
- 6 Derive Keying Data.

a Hash-1 = Z || 00 00 00 01 || SharedData

b Hash-2 = Z || 00 00 00 02 || SharedData

- c KeyingData = Hash-1 || Hash-2
- 7 Parse Keying Data as follows:
 - a MacKey = First 128 bits (Hash-1) of KeyingData
 - b KeyData = Second 128 bits (Hash-2) of KeyingData
- 8 Form the bit string MacData2.
 - a MacData2 = 03 || U || V || QEU || QEV || Text2
- 9 Calculate MacTag2.
 - a MacTag2 = MAC(MacData2, MacKey)
- 10 Send MacTag2 and Text2 to Responder (SKKE-3).
- 11 Receive MacTag1' and Text1 from Responder (SKKE-4).
- 12 Create bit string MacData1.
 - a MacData1 = 02 || V || U || QEV || QEU || Text1
- 13 Verify MacTag1 and MacTag1' match.
 - a MacTag1 = MAC(MacData1, MacKey)
 - b Check MacTag1 == MacTag1'
- 14 Store new Link Key, KeyData. (SKKE).

C.6.4.3 SKKE Test Vector #1

Initiator IEEE Address (U)	(>) 11 11 11 11 11 11 11 11
Responder IEEE Address (V)	(>) 22 22 22 22 22 22 22 22
Master Key (Key)	(<) 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Initiator Challenge (QEU)	(<) 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Responder Challenge (QEV)	(<) 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
SKKE-3 Data (MacTag2)	(<) F9 A0 89 6C E2 73 8D 71 34 3D 27 9B 51 3F 07 9C
SKKE-4 Data (MacTag1)	(<) 55 98 10 E9 BD A4 48 40 59 88 12 58 C1 B2 0A 4F
Derived Link Key	(<) 19 BB FC 94 57 55 E7 09 86 E8 8B 5D 21 1C 97 37

Intermediate Steps

- 1 Responder's EUI 64 (V) must be known ahead of time
- 2 Generate Initiator Challenge QEU
- 3 Send Initiator Challenge and Initiator EUI64 to Responder (SKKE-1)
- 4 Receive Responder Challenge, QEV (SKKE-2)
- 5 Calculate shared secret bit string Z.

a MacData1 = U || V || QUE || QEV

0x11	0x11	0x11	0x11	0x11	0x11	0x11	0x11
0x22	0x22	0x22	0x22	0x22	0x22	0x22	0x22
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00

b MacTag1 = MAC(MacData1, Key)

c Z = MacTag1

0x4c	0x3f	0x60	0xa0	0x2e	0x07	0x13	0x5e
0xdf	0xad	0xb0	0xe0	0xc1	0x46	0xfd	0xe2

6 Derive Keying Data

a Hash-1 = Z || 00 00 00 01 || SharedData

Bit String (before Hash)

0x4c	0x3f	0x60	0xa0	0x2e	0x07	0x13	0x5e
0xdf	0xad	0xb0	0xe0	0xc1	0x46	0xfd	0xe2
0x00	0x00	0x00	0x01				

b Hash-2 = Z || 00 00 00 02 || SharedData

Bit String (before Hash)

0x4c	0x3f	0x60	0xa0	0x2e	0x07	0x13	0x5e
0xdf	0xad	0xb0	0xe0	0xc1	0x46	0xfd	0xe2
0x00	0x00	0x00	0x02				

c KeyingData = Hash-1 || Hash-2

7 Parse Keying Data as follows:

a MacKey = First 128 bits (Hash-1) of KeyingData

0xaf	0x6e	0x2b	0x7a	0x59	0xc0	0x98	0xb0
0xcf	0x0a	0x93	0x1c	0x8b	0x34	0xcd	0xbd

b KeyData = Second 128 bits (Hash-2) of KeyingData

0x19	0xbb	0xfc	0x94	0x57	0x55	0xe7	0x09
0x86	0xe8	0x8b	0x5d	0x21	0x1c	0x97	0x37

8 Form the bit string MacData2.

a MacData2 = 03 || U || V || QEU || QEV || Text2

0x03	0x11	0x11	0x11	0x11	0x11	0x11	0x11
0x11	0x22	0x22	0x22	0x22	0x22	0x22	0x22
0x22	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00

9 Calculate MacTag2.

a MacTag2 = MAC(MacData2, MacKey)

0xf9	0xa0	0x89	0x6c	0xe2	0x73	0x8d	0x71
0x34	0x3d	0x27	0x9b	0x51	0x3f	0x07	0x9c

10 Send MacTag2 and Text2 to Responder (SKKE-).

11 Receive MacTag1' and Text1 from Responder (SKKE-4).

12 Create bit string MacData1.

a MacData1 = 02 || V || U || QEV || QEU || Text1

0x02	0x22	0x22	0x22	0x22	0x22	0x22	0x22
0x22	0x11	0x11	0x11	0x11	0x11	0x11	0x11
0x11	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00
0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00

13 Verify MacTag1 and MacTag1' match.

a MacTag1 = MAC(MacData1, MacKey)

0x55	0x98	0x10	0xe9	0xbd	0xa4	0x48	0x40
0x59	0x88	0x12	0x58	0xc1	0xb2	0x0a	0x4f

14 Verify MacTag1 and MacTag1' match.

- a MacTag1 = MAC(MacData1, MacKey)
- b Check MacTag1 == MacTag1'
- 15Store new Link Key, KeyData. (SKKE).

0x19 0xbb 0xfc 0x94 0x57 0x55 0xe7 0x09

0x86 0xe8 0x8b 0x5d 0x21 0x1c 0x97 0x37

C.6.4.4 SKKE Test Vector #2

Initiator IEEE Address (U)	(>) 55 73 65 72 20 55 0D 0A
Responder IEEE Address (V)	(>) 55 73 65 72 20 56 0D 0A
Master Key (Key)	(<) C0 C1 C2 C3 C4 C5 C6 C7 C8 C9 CA CB CC CD CE CF
Initiator Challenge (QEU)	(<) 9E 3F 0C 19 05 4B 05 44 D5 A7 17 62 0A F2 7D 96
Responder Challenge (QEV)	(<) BF 14 DF 94 94 39 D2 CE 24 C9 09 53 B5 72 D6 53
SKKE-3 Data (MacTag2)	(<) 57 E1 D4 F9 7B 28 AB 72 B1 9B B7 76 F7 B5 55 1C
SKKE-4 Data (MacTag1)	(<) A0 31 57 12 38 6A 25 EF 28 94 30 6C 6F BA A4 DA
Derived Link Key	(<) 84 3D 71 7F 92 C3 D4 31 0A 9F 46 6B 58 B9 F2 1C

Intermediary Steps

- 1 Responder's EUI 64 (V) must be known ahead of time.
- 2 Generate Initiator Challenge QEU.
- 3 Send Initiator Challenge and Initiator EUI64 to Responder (SKKE-1).
- 4 Receive Responder Challenge, QEV (SKKE-2).
- 5 Calculate shared secret bit string Z.
- a MacData1 = U || V || QEU || QEV

0x55 0x73 0x65 0x72 0x20 0x55 0x0d 0x0a

0x55 0x73 0x65 0x72 0x20 0x56 0x0d 0x0a

0x9e 0x3f 0x0c 0x19 0x05 0x4b 0x05 0x44

0xd5 0xa7 0x17 0x62 0x0a 0xf2 0x7d 0x96

0xbf 0x14 0xdf 0x94 0x94 0x39 0xd2 0xce

0x24 0xc9 0x09 0x53 0xb5 0x72 0xd6 0x53

b MacTag1 = MAC(MacData1, Key)

c Z = MacTag1

0x78	0x7c	0xde	0xf6	0x80	0x13	0x12	0xcd
0x41	0x1b	0xcd	0x62	0x14	0x91	0xf8	0x6d

6 Derive Keying Data

a Hash-1 = Z || 00 00 00 01 || SharedData

Bit String (before Hash)

0x78	0x7c	0xde	0xf6	0x80	0x13	0x12	0xcd
0x41	0x1b	0xcd	0x62	0x14	0x91	0xf8	0x6d
0x00	0x00	0x00	0x01				

b Hash-2 = Z || 00 00 00 02 || SharedData

Bit String (before Hash)

0x78	0x7c	0xde	0xf6	0x80	0x13	0x12	0xcd
0x41	0x1b	0xcd	0x62	0x14	0x91	0xf8	0x6d
0x00	0x00	0x00	0x02				

c KeyingData = Hash-1 || Hash-2

7 Parse Keying Data as follows:

a MacKey = First 128 bits (Hash-1) of KeyingData

0x0e	0x6b	0x9f	0x70	0x8c	0xaa	0x84	0x63
0x44	0x76	0xec	0x17	0xa4	0x3e	0x6b	0xc5

b KeyData = Second 128 bits (Hash-2) of KeyingData

0x84	0x3d	0x71	0x7f	0x92	0xc3	0xd4	0x31
0x0a	0x9f	0x46	0x6b	0x58	0xb9	0xf2	0x1c

8 Form the bit string MacData2

a MacData2 = 03 || U || V || QEU || QEV || Text2

0x03	0x55	0x73	0x65	0x72	0x20	0x55	0x0d
0x0a	0x55	0x73	0x65	0x72	0x20	0x56	0x0d
0x0a	0x9e	0x3f	0x0c	0x19	0x05	0x4b	0x05
0x44	0xd5	0xa7	0x17	0x62	0x0a	0xf2	0x7d
0x96	0xbf	0x14	0xdf	0x94	0x94	0x39	0xd2
0xce	0x24	0xc9	0x09	0x53	0xb5	0x72	0xd6
0x53							

9 Calculate MacTag2**a** MacTag2 = MAC(MacData2, MacKey)

0x57	0xe1	0xd4	0xf9	0x7b	0x28	0xab	0x72
0xb1	0x9b	0xb7	0x76	0xf7	0xb5	0x55	0x1c

10 Send MacTag2 and Text2 to Responder (SKKE-3).**11** Receive MacTag1' and Text1 from Responder (SKKE-4).**12** Create bit string MacData1**a** MacData1 = 02 || V || U || QEV || QEU || Text1

0x02	0x55	0x73	0x65	0x72	0x20	0x56	0x0d
0x0a	0x55	0x73	0x65	0x72	0x20	0x55	0x0d
0x0a	0xbf	0x14	0xdf	0x94	0x94	0x39	0xd2
0xce	0x24	0xc9	0x09	0x53	0xb5	0x72	0xd6
0x53	0x9e	0x3f	0x0c	0x19	0x05	0x4b	0x05
0x44	0xd5	0xa7	0x17	0x62	0x0a	0xf2	0x7d
0x96							

13 Verify MacTag1 and MacTag1' match**a** MacTag1 = MAC(MacData1, MacKey)

0xa0	0x31	0x57	0x12	0x38	0x6a	0x25	0xef
0x28	0x94	0x30	0x6c	0x6f	0xba	0xa4	0xda

b Check MacTag1 == MacTag1'**14** Store new Link Key, KeyData. (SKKE), or

0x84	0x3d	0x71	0x7f	0x92	0xc3	0xd4	0x31
0x0a	0x9f	0x46	0x6b	0x58	0xb9	0xf2	0x1c

C.6.4.5 Entity Authentication Initiator Transform

Term	Description
MacKey	Shared Key (Network Key)
U	Initiator's unique ID (EUI64 Address)
V	Responder's unique ID (EUI64 Address)
QEU	Initiator Challenge (16 byte random number)
QEV	Responder Challenge (16 byte random number)
MAC	Our HMAC Function
Text1	Optional bit string. The Frame Counter in EA
Text2	""
SharedData	Optional data shared between initiator and responder. An empty string for SKKE / EA.

Note: '||' in this pseudo-code means concatenation

- 1 Responder's EUI 64 (V) must be known ahead of time.
- 2 Generate Initiator Challenge QEU.
- 3 Send Initiator Challenge and Initiator IEEE to Responder (EA-Init-Challenge).
- 4 Receive Responder Challenge, QEV (EA-Resp-Challenge).
- 5 Form the bit string MacData2
 - a $\text{MacData2} = 03 \parallel U \parallel V \parallel \text{QEU} \parallel \text{QEV} \parallel \text{Text2}$
- 6 Calculate MacTag2
 - a $\text{MacTag2} = \text{MAC}(\text{MacData2}, \text{MacKey})$
- 7 Send MacTag2 and Text2 to Responder (EA-Init-Mac-Data).
- 8 Receive MacTag1' and Text1 from Responder (EA-Resp-Mac-Data).
- 9 Create bit string MacData1
 - a $\text{MacData1} = 02 \parallel V \parallel U \parallel \text{QEV} \parallel \text{QEU} \parallel \text{Text1}$
- 10 Verify MacTag1 and MacTag1' match
 - a $\text{MacTag1} = \text{MAC}(\text{MacData1}, \text{MacKey})$
 - b Check $\text{MacTag1} == \text{MacTag1}'$

11 Store new Frame Counter, Text1 (EA).

C.6.4.6 EA Test Vector #1

Initiator IEEE Address (U)	(>) 22 22 22 22 22 22 22 22
Responder IEEE Address (V)	(>) 11 11 11 11 11 11 11 11
Network Key (MacKey)	(<) 44 44 44 44 44 44 44 44 44 44 44 44 44 44 44
Initiator Challenge (QUE)	(<) 55 55 55 55 55 55 55 55 55 55 55 55 55 55 55
Responder Challenge (QEV)	(<) 66 66 66 66 66 66 66 66 66 66 66 66 66 66 66
EA Initiator Data (MacTag2)	(<) b5 8e 4a a8 ce 51 06 bc 5e 71 9a 41 3e 2e 6e 94
EA Responder Data (MacTag1)	(<) 83 75 96 ff 23 ea 8c 54 2a 9c 0d 7e 8c c4 ca b4
Initiator Frame Counter (Text2)	(<) 00 00 00 00
Responder Frame Counter (Text1)	(<) 00 00 00 00

Intermediate Steps

- 1 Responder's EUI 64 (V) must be known ahead of time.
- 2 Generate Initiator Challenge QEU.
- 3 Send Initiator Challenge and Initiator IEEE to Responder (EA-Init-Challenge).
- 4 Receive Responder Challenge, QEV (EA-Resp-Challenge).
- 5 Form the bit string MacData2

a MacData2 = 03 || U || V || QEU || QEV || Text2

0x03	0x22	0x22	0x22	0x22	0x22	0x22	0x22
0x22	0x11	0x11	0x11	0x11	0x11	0x11	0x11
0x11	0x55	0x55	0x55	0x55	0x55	0x55	0x55
0x55	0x55	0x55	0x55	0x55	0x55	0x55	0x55
0x55	0x66	0x66	0x66	0x66	0x66	0x66	0x66
0x66	0x66	0x66	0x66	0x66	0x66	0x66	0x66
0x66	0x00	0x00	0x00	0x00			

- 6 Calculate MacTag2

a MacTag2 = MAC(MacData2, MacKey)

0xb5	0x8e	0x4a	0xa8	0xce	0x51	0x06	0xbc
0x5e	0x71	0x9a	0x41	0x3e	0x2e	0x6e	0x94

7 Send MacTag2 and Text2 to Responder (EA-Init-Mac-Data).

8 Receive MacTag1' and Text1 from Responder (EA-Resp-Mac-Data).

9 Create bit string MacData1

a MacData1 = 02 || V || U || QEV || QEU || Text1

0x02	0x11	0x11	0x11	0x11	0x11	0x11	0x11
0x11	0x22	0x22	0x22	0x22	0x22	0x22	0x22
0x22	0x66	0x66	0x66	0x66	0x66	0x66	0x66
0x66	0x66	0x66	0x66	0x66	0x66	0x66	0x66
0x66	0x55	0x55	0x55	0x55	0x55	0x55	0x55
0x55	0x55	0x55	0x55	0x55	0x55	0x55	0x55
0x55	0x00	0x00	0x00	0x00			

10 Verify MacTag1 and MacTag1' match

a MacTag1 = MAC(MacData1, MacKey)

0x83	0x75	0x96	0xff	0x23	0xea	0x8c	0x54
0x2a	0x9c	0x0d	0x7e	0x8c	0xc4	0xca	0xb4

b Check MacTag1 == MacTag1'

11 Store new Frame Counter, Text1 (EA).

C.6.4.7 EA Test Vector #2

Initiator IEEE Address (U)	(>) ab cd ef 01 23 45 67 89
Responder IEEE Address (V)	(>) 12 34 56 78 90 ab cd ef
Network Key (MacKey)	(<) 47 85 67 85 73 11 79 85 43 21 87 57 44 35 02 65
Initiator Challenge (QUE)	(<) 43 4f 85 a1 61 d3 ba 99 7b 3f 25 ef 00 34 42 6f
Responder Challenge (QEV)	(<) e2 08 74 50 4a 0f 18 97 40 9d fb d0 49 78 ae 69
EA Initiator Data (MacTag2)	(<) 9b f9 e2 48 5d 14 a8 be 6d 40 d3 ee c2 0d e6 6d
EA Responder Data (MacTag1)	(<) 67 59 9c a8 a3 1f 8e b0 87 9a de d3 7c ba fc c5
Initiator Frame Counter (Text2)	(<) 1f 00 00 00
Responder Frame Counter (Text1)	(<) 20 00 00 00

Intermediate Steps

- 1 Responder's EUI 64 (V) must be known ahead of time
- 2 Generate Initiator Challenge QEU
- 3 Send Initiator Challenge and Initiator IEEE to Responder (EA-Init-Challenge)
- 4 Receive Responder Challenge, QEV (EA-Resp-Challenge)
- 5 Form the bit string MacData2

a MacData2 = 03 || U || V || QEU || QEV || Text2

0x03 0xab 0xcd 0xef 0x01 0x23 0x45 0x67

0x89 0x12 0x34 0x56 0x78 0x90 0xab 0xcd

0xef 0x43 0x4f 0x85 0xa1 0x61 0xd3 0xba

0x99 0x7b 0x3f 0x25 0xef 0x00 0x34 0x42

0x6f 0xe2 0x08 0x74 0x50 0x4a 0x0f 0x18

0x97 0x40 0x9d 0xfb 0xd0 0x49 0x78 0xae

0x69 0x00 0x00 0x00 0x1f

- 6 Calculate MacTag2
- a MacTag2 = MAC(MacData2, MacKey)

0x9b 0xf9 0xe2 0x48 0x5d 0x14 0xa8 0xbe

0x6d 0x40 0xd3 0xee 0xc2 0x0d 0xe6 0x6d

- 7** Send MacTag2 and Text2 to Responder (EA-Init-Mac-Data)
- 8** Receive MacTag1' and Text1 from Responder (EA-Resp-Mac-Data)
- 9** Create bit string MacData1
 - a** MacData1 = 02 || V || U || QEV || QEU || Text1

0x02	0x12	0x34	0x56	0x78	0x90	0xab	0xcd
0xef	0xab	0xcd	0xef	0x01	0x23	0x45	0x67
0x89	0xe2	0x08	0x74	0x50	0x4a	0x0f	0x18
0x97	0x40	0x9d	0xfb	0xd0	0x49	0x78	0xae
0x69	0x43	0x4f	0x85	0xa1	0x61	0xd3	0xba
0x99	0x7b	0x3f	0x25	0xef	0x00	0x34	0x42
0x6f	0x00	0x00	0x00	0x20			
- 10** Verify MacTag1 and MacTag1' match
 - a** MacTag1 = MAC(MacData1, MacKey)

0x67	0x59	0x9c	0xa8	0xa3	0x1f	0x8e	0xb0
0x87	0x9a	0xde	0xd3	0x7c	0xba	0xfc	0xc5
 - b** Check MacTag1 == MacTag1'
- 11** Store new Frame Counter, Text1 (EA)

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A N N E X

D

MAC AND PHY SUB-LAYER
CLARIFICATIONS

D.1 Introduction

D.1.1 Scope

This annex applies to the IEEE 802.15.4 2003 Medium Access Control sub-layer (MAC) and Physical Layer (PHY) specification when used in conjunction with higher layers defined by the ZigBee specification. Nothing is implied about the usage under other circumstances.

D.1.2 Purpose

The current ZigBee specification assumes the use of the MAC and PHY sub-layers defined in the IEEE 802.15.4 2003 specification. However, as developers have put the MAC and PHY sub-layers into use, they have uncovered problems that may or may not have been anticipated by the authors of the specification, or are not covered in the IEEE 802.15.4 2003 specification. This document is intended to provide solutions to such problems, for use by the ZigBee Alliance.

D.2 Stack Size Issues

Both MAC and ZigBee stack developers have discovered that implementation of a full-blown MAC is a major undertaking and requires a great deal of code space. Even with the optional GTS and MAC security features eliminated, it is not surprising to find the MAC taking up more than 24K of code space on a processor with 64K of available space.

The ZigBee Alliance has adopted a compensating policy to declare MAC features that are not required to support a particular stack profile optional with respect to that stack profile. In particular, any MAC feature that will not be exploited as a result of platform compliance testing for a particular stack profile need not be present in order for an implementation to be declared platform compliant. For example, since the ZigBee 2006 stack profile relies on a beaconless network, the platform compliance testing for the stack profile does not employ beaconing. The code to support regular beaconing, beacon track, and so on, may therefore be absent from the code base of the device under test without the knowledge of the testers, without presenting a problem with respect to platform compliance certification.

D.3 MAC Association

At association time, according to the IEEE 802.15.4 2003 specification, a number of frames are sent, including an association request command, an associate response command and a data request. There is some ambiguity in the specification regarding the addressing fields in the headers for these frames. Tables D.1–D.3 outline the allowable options that shall be recognized by devices implementing the ZigBee specification. In each case, the first option given is the preferred option and should be used.

Table D.1 Associate Request Header Fields

DstPANId	DstAddr	SrcPANId	SrcAddr
The PANId of the destination device.	The 16-bit short address of the destination device.	0xffff	The 64-bit extended address of the source device.
		PANId omitted because the IntraPAN sub-field in the frame control field is set to one.	
		The PANId of the destination device.	
Not present if the destination device is the PAN coordinator.	Not present if the destination device is the PAN coordinator.		

Note that in this case and the case below, the source of the command is the device requesting association.

Table D.2 Data Request Header Fields

DstPANId	DstAddr	SrcPANId	SrcAddr
The PANId of the destination device.	The 16-bit short address of the destination device.	0xffff	The 64-bit extended address of the source device.
		PANId omitted because the IntraPAN sub-field in the frame control field is set to one.	
		The PANId of the destination device.	
Not present if the destination device is the PAN coordinator.	Not present if the destination device is the PAN coordinator.		

Table D.3 Association Response Header Fields

DstPANId	DstAddr	SrcPANId	SrcAddr
The PANId of the destination device.	The 64-bit extended address of the destination device.	PANId omitted because the IntraPAN sub-field in the frame control field is set to one.	The 64-bit extended address of the source device.
		The PANId of the source device.	
0xffff			

D.4 *aMaxMACFrameSize*

In the IEEE 802.15.4 2003 specification, there is a constant called *aMaxMACFrameSize* which is defined as being *aMaxPHYPacketSize* - *aMaxFrameOverhead*. This formula gives $aMaxMACFrameSize = 127 - 25 = 102$ bytes. The disagreement about this value relates to the *aMaxFrameOverhead* parameter. The value of 25 for this constant is not correct for a ZigBee network in which only short addressing modes can be used. The ZigBee alliance decided that, rather than arguing what the correct value of *aMaxFrameOverhead* should be, an acceptable packet is defined as one that is less than *aMaxPHYFrameSize* and is a decodable 802.15.4 and ZigBee packet.

To facilitate this, the maximum sizes for the `NsduLength` parameters are defined as less than $aMaxPHYFrameSize - (nwkcMACFrameOverhead + nwkcMinHeaderOverhead)$. Developers of ZigBee solutions therefore need to ensure that their 802.15.4 implementations are able to accommodate this enhancement.

D.5 Beacon Timing

In order to employ the NWK beacon scheduling algorithm, it is necessary to implement the following enhancement to the IEEE Std 802.15.4-2003 MAC sub-layer.

A new parameter, `StartTime`, shall be added to the `MLME-START.request` primitive to specify the time to begin transmitting beacons. The new format of the primitive is as follows:

MLME-START.request	{
	PANID,
	LogicalChannel,
	BeaconOrder,
	SuperframeOrder,
	PANCoordinator,
	BatteryLifeExtention,
	CoordRealignment,
	SecurityEnable,
	StartTime
	}

The StartTime parameter is fully described in Table D.4, and the description of all other parameters can be found in IEEE 802.15.4-2003 [B1].

Table D.4 Start Time for Beacon Transmissions

Name	Type	Valid Range	Description
StartTime	Integer	0x000000 – 0xfffff	The time at which to begin transmitting beacons. If the device issuing the primitive is the PAN coordinator, this parameter is ignored and beacon transmissions will begin immediately. Otherwise, this parameter specifies the time relative to its parent’s beacon. The parameter is specified in symbols and is rounded to a backoff slot boundary. The precision of this value is a minimum of 20 bits, with the lowest 4 bits being the least significant.

The value of macAutoRequest shall be set to the default value in IEEE 802.15.4 [B1].

D.6 CSMA Backoff Timing

The IEEE 802.15.4 2006 specification provides an increase in macMaxBE to 8 from 5. This higher value is allowed within ZigBee and it is recommended as the default. The default value of macMinBE should be 5 instead of 3. This provides better joining performance in dense networks where many devices may be responding to a beacon request.

Note the time a device listens for beacons is set by IEEE 802.15.4 to $aBaseSuperframeDuration \cdot (2n+1)$ symbols where n is the value of the *ScanDuration* parameter. For ZigBee implementations the value of n should be set to ensure the duration of the listening window is similar to the length of time the beacon responses are expected.

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A N N E X

E

OPERATION OF NETWORK MANAGER AS NETWORK CHANNEL MANAGER FOR INTERFERENCE REPORTING AND RESOLUTION

Prerequisites: Devices shall limit their operations to channels within their current PHY (i.e. 868/915 MHz or 2450 MHz). Commands including channels outside the band shall be ignored.⁴⁶

A single device can become the Network Channel Manager. This device acts as the central mechanism for reception of network interference reports and changing the channel of the network if interference is detected. The default address of the network manager is the coordinator, however this can be updated by sending a Mgmt_NWK_Update_req command with a different short address for the network channel manager. The device that is the Network Channel Manager shall set the network manager bit in the server mask in the node descriptor and shall respond to System_Server_Discovery_req commands.

Each router or coordinator is responsible for tracking transmit failures using the TransmitFailure field in the neighbor table and also keeping a NIB counter for total transmissions attempted. Once the total transmissions attempted is over 20, if the transmit failures exceeds 25% of the messages sent, the device may have detected interference on the channel in use. The device is then responsible for taking the following steps:

- 1 Conduct an energy scan on all channels within the current PHY.⁴⁷ If this energy scan does not indicate higher energy on the current channel then other channels, no action is taken. The device should continue to operate as normal

46. ZigBee Document 12-0220-04

47. ZigBee Document 12-0220-04

and the message counters are not reset. However, repeated energy scans are not desirable as the device is off the network during these scans and therefore implementations should limit how often a device with failures conducts energy scans.

- 2 If the energy scan does indicate increased energy on the channel in use, a `Mgmt_NWK_Update_notify` should be sent to the Network Manager to indicate interference is present. This report is sent as an APS Unicast with acknowledgement and once the acknowledgment is received the total transmit and transmit failure counters are reset to zero.
- 3 To avoid a device with communication problems from constantly sending reports to the network manager, the device should not send a `Mgmt_NWK_Update_notify` more than 4 times per hour.

Upon receipt of an unsolicited `Mgmt_NWK_Update_notify`, the network manager must evaluate if a channel change is required in the network. The specific mechanisms the network manager uses to decide upon a channel change are left to the implementers. It is expected that implementers will apply different methods to best determine when a channel change is required and how to select the most appropriate channel. The following is offered as guidance for implementation.

The network manager may do the following:

- 1 Wait and evaluate if other reports from other devices are received. This may be appropriate if there are no other failures reported. In this case the network manager should add the reporting device to a list of devices that have reported interference. The number of devices on such a list would depend on the size of the network. The network manager can age devices out of this list.
- 2 Request other interference reports using the `Mgmt_NWK_Update_req` command. This may be done if other failures have been reported or the network manager device itself has failures and a channel change may be desired. The network manager may request data from the list of devices that have reported interference plus other randomly selected routers in the network. The network manager should not request an update from the device that has just reported interference since this data is fresh already.
- 3 Upon receipt of the `Mgmt_NWK_Update_notify`, the network manager shall determine if a channel change is required using whatever implementation specific mechanisms are considered appropriate. The network manager device with just one channel allowed in the `apsChannelMask` parameter must not issue the `Mgmt_Nwk_Update_Req` command to request other devices to change the current channel. However, the network manager may report channel quality issues to the application.⁴⁸

48. ZigBee Document 12-0220-04

4 If the above data indicate a channel change should be considered, the network manager completed the following:

- a Select a single channel based on the `Mgmt_NWK_Update_notify` based on the lowest energy. This is the proposed new channel. If this new channel does not have an energy level below an acceptable threshold, a channel change should not be done. Additionally, a new channel shall not belong to a PHY different from the one on which a network manager is operating now.⁴⁹

5 Prior to changing channels, the network manager should store the energy scan value as the last energy scan value and the failure rate from the existing channel as the last failure rate. These values are useful to allow comparison of the failure rate and energy level on the previous channel to evaluate if the network is causing its own interference.

6 The network manager should broadcast a `Mgmt_NWK_Update_req` notifying devices of the new channel. The broadcast shall be to all devices with `RxOnWhenIdle` equal to `TRUE`. The network manager is responsible for incrementing the `nwkUpdateId` parameter from the NIB and including it in the `Mgmt_NWK_Update_req`. The network manager shall set a timer based on the value of `apsChannelTimer` upon issue of a `Mgmt_NWK_Update_req` that changes channels and shall not issue another such command until this timer expires. However, during this period, the network manager can complete the above analysis. However, instead of changing channels, the network manager would report to the local application using `Mgmt_NWK_Update_notify` and the application can force a channel change using the `Mgmt_NWK_Update_req`.

Upon receipt of a `Mgmt_NWK_Update_req` with a change of channels, the local network manager shall set a timer equal to the `nwkNetworkBroadcastDeliveryTime` and shall switch channels upon expiration of this timer. Each node shall also increment the `nwkUpdateId` parameter and also reset the total transmit count and the transmit failure counters.

For devices with `RxOnWhenIdle` equals `FALSE`, any network channel change will not be received. On these devices or routers that have lost the network, an active scan shall be conducted on the `apsChannelMask` list in the APS IB using the extended PANID to find the network. If the extended PANID is found on different channels, the device should select the channel with the higher value in the `nwkUpdateId` parameter. If the extended PANID is not found using the `apsChannelMask` list, a scan should be completed using all channels within the current PHY.⁵⁰

49. ZigBee Document 12-0220-04

50. ZigBee Document 12-0220-04

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F

USAGE OF MULTIPLE FREQUENCY BANDS

F.1 Introduction

F.1.1 Scope

This annex clarifies uncertainties arising with ZigBee compliant devices that support several frequency bands.

F.1.2 Purpose

The ZigBee specification is based on the IEEE 802.15.4 2003 ([B1]) standard that declares two PHYs: an 868/915 MHz direct sequence spread spectrum (DSSS) PHY and a 2450 MHz DSSS PHY. These two PHYs can operate on the three different frequency bands: 868 MHz, 915 MHz and 2450 MHz. A compliant device shall operate in one or several frequency bands. The frequency bands combinations must meet regional regulatory requirements described in the IEEE 802.15.4 2003 standard. Each of the frequency bands incorporates its own set of channels: channel 0 for the 868 MHz band, channels from 1 to 10 for the 915 MHz band and channels from 11 to 26 for the 2450 MHz band. The IEEE 802.15.4 2003 standard also requires the following:

- A device declaring support of a frequency band shall support all the channels within this frequency band (IEEE P802.15.4 §6.1.2 [B1])
- A device declaring support of the 868/915 MHz PHY shall support both 868 MHz and 915 MHz frequency bands within this PHY (IEEE P802.15.4, §C.7.2.3 [B1])

From the very beginning, initial versions of ZigBee specification assumed that a ZigBee compliant device can use any of the frequency bands described in the IEEE 802.15.4 2003 standard. But in real life for a rather long period of time only the 2450 MHz frequency band was used by almost all vendors implementing

ZigBee stacks. Later, on market request, some implementations of the ZigBee stack running on non-2450 MHz frequency bands appeared. These implementations revealed some uncertainties within the ZigBee specification. This annex is intended to eliminate these uncertainties by highlight points of usage of different frequency bands by a ZigBee compliant device.

F.2 Channels and Channel Masks Management General Guideline

F.2.1 Channel Selection During Network Establishment

When there is a set of devices intended to be a part of the same ZigBee network, with devices of that set, potentially, supporting different frequency bands, the coordinator, during network establishment, may choose a channel from a frequency band that is not supported by some of the other devices.

Since, before a network is established, there is no mechanism for the coordinator to dynamically collect information about frequency bands supported on each and every device in the network, this issue may be categorized as a network commissioning issue and has to be resolved in the layers above the ZigBee stack's core.

F.2.2 The Frequency Agility Feature Related Points

How a network manager or a device shall behave, considering the ability to support different frequency bands, is described in Annex E and in sub-clause 2.4.3.3.9.2, "Effect on Receipt". Implementers of the frequency agility feature should take into account that it is prohibited for a network manager device to move a network from one PHY to another. This limitation is introduced in order to avoid the situations when a part of devices in the network cannot physically migrate to a channel from another PHY and therefore got lost. At the same time moving a network from one frequency band to another within 868/915 MHz PHY is allowed since support of both bands is mandatory in accordance with IEEE P802.15.4 (§C.7.2.3 [B1]). The application layer must meet regional regulatory requirements by setting an appropriate value to the *apsChannelMask* parameter.

F.2.3 Network Management Services and Client Services Affected by Multiple Frequency Bands Support

The following Network Management Client Services and Network Management Services use the *ScanChannels* parameter and, therefore, have to be mentioned in

regard of multiple frequency bands support: Mgmt_NWK_Disc_req, Mgmt_NWK_Update_req and NLME-JOIN.request. In case the *ScanChannels* bitmask includes a channel(s) from unsupported frequency band the INVALID_PARAMETER (see [B1]) error status is supposed to be raised from the MAC layer to the NWK layer. If the destination addressing mode in the Mgmt_NWK_Disc_req and Mgmt_NWK_Update_req commands was unicast then the Remote Device shall incorporate the error status into the status field of the correspondent Mgmt_NWK_Disc_rsp and Mgmt_NWK_Update_rsp commands. The same error status shall be reported in NLME-JOIN.confirm primitive sent in response to an NLME-JOIN.request primitive if the latter contains unsupported channels.

In case the NLME-JOIN.request primitive is used by the application layer to request a device to switch to a new channel (the *RejoinNetwork* parameter is equal to 0x03) then the application layer, by implementation-specific means, has to ensure that the chosen channel is supported by all other devices in the network, to avoid the situation when some of the devices might be lost from the network due to inability to switch to an unsupported channel.

F.3 Timing Issues

Different frequency bands declared in the IEEE 802.15.4 2003 standard provide different bit rates. Therefore the ZigBee stack's time-related parameters have to be adjusted accordingly to achieve the stable operation on each of the supported frequency bands. The ZigBee stack's time-related parameters can be divided in two groups in regard of multiple frequency bands support: the first group includes time-related parameters that have a direct impact on the ZigBee stack's core's functioning and that ensure that the core's functioning is correct; the second group consists of the time-related parameters that have to be configured by an application. The ZigBee specification controls the first group of parameters and declares them in a way that makes them dependent on the currently used frequency band. These parameters are presented in Table F.1 and their values must be updated automatically each time a device migrates from one frequency band to another.

Table F.1 Internal Time-related Parameters

Parameter	Reference
<i>:Config_NWK_Time_btwn_Scans</i>	Sub-clause 2.5.6.1, Table 2.149, page 257
<i>nwkcWaitBeforeValidation</i>	Sub-clause 3.5.1, Table 3.43, page 341
<i>nwkcRouteDiscoveryTime</i>	Sub-clause 3.5.1, Table 3.43, page 341
<i>nwkcMaxBroadcastJitter</i>	Sub-clause 3.5.1, Table 3.43, page 341
<i>nwkcRREQRetryInterval</i>	Sub-clause 3.5.1, Table 3.43, page 342

Table F.1 Internal Time-related Parameters (Continued)

Parameter	Reference
<i>nwkcMinRREQJitter</i>	Sub-clause 3.5.1, Table 3.43, page 342
<i>nwkcMaxRREQJitter</i>	Sub-clause 3.5.1, Table 3.43, page 342
<i>nwkPassiveAckTimeout</i>	Sub-clause 3.5.2, Table 3.44, page 343
<i>nwkNetworkBroadcastDeliveryTime</i>	Sub-clause 3.5.2, Table 3.44, page 344
<i>apsSecurityTimeOutPeriod</i>	Sub-clause 4.4.10 Table 4.36, page 497

51