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Wireless LAN Control Protocol (WiCoP)

Abstract

The popularity of wireless local area networks (WLANs) has led to widespread deployments across different establishments. It has also translated into an increasing scale of the WLANs. Large-scale deployments made of large numbers of wireless termination points (WTPs) and covering substantial areas are increasingly common.

The Wireless LAN Control Protocol (WiCoP) described in this document allows for the control and provisioning of large-scale WLANs. It enables central management of these networks and realizes the objectives set forth for the Control And Provisioning of Wireless Access Points (CAPWAP).

Status of This Memo

This document is not an Internet Standards Track specification; it is published for the historical record.

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Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc5414.

IESG Note

This RFC documents the WiCoP protocol as it was when submitted to the IETF as a basis for further work in the CAPWAP Working Group, and therefore it may resemble the CAPWAP protocol specification in RFC 5415, as well as other IETF work. This RFC is being published solely for the historical record. The protocol described in this RFC has not been thoroughly reviewed and may contain errors and omissions.

RFC 5415 documents the standards track solution for the CAPWAP Working Group and obsoletes any and all mechanisms defined in this RFC. This RFC itself is not a candidate for any level of Internet Standard and should not be used as a basis for any sort of Internet deployment.

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1. Introduction

The popularity of wireless local area networks (WLANs) has led to numerous but incompatible designs and solutions. The CAPWAP Architecture Taxonomy [RFC4118] describes major variations of these designs. Among them, the Local MAC (Media Access Control) and Split MAC architecture designs are notable categories.

Wireless LAN Control Protocol (WiCoP) recognizes the major architecture designs and presents a common platform on which WLAN entities of different designs can be accommodated. This enables interoperability among wireless termination points (WTPs) and WLAN access controllers (ACs) of distinct architecture designs. WiCoP therefore allows for cost-effective WLAN expansions. It can also accommodate future developments in WLAN technologies. Figure 1 illustrates the WiCoP operational structure in which distinct control elements are utilized for Local MAC and Split MAC WTPs.

WiCoP also addresses the increasing trend of shared infrastructure WLANs. Here, WLAN management needs to distinguish and isolate control for the different logical groups sharing a single physical WLAN. WiCoP manages WLANs through a series of tunnels that separate traffic based on logical groups.

The WiCoP operational structure in Figure 1 shows that each WTP uses a number of tunnels to distinguish and separate traffic for control and for each logical group. The protocol allows for managing WLANs in a manner consistent with the logical groups that share the physical infrastructure.

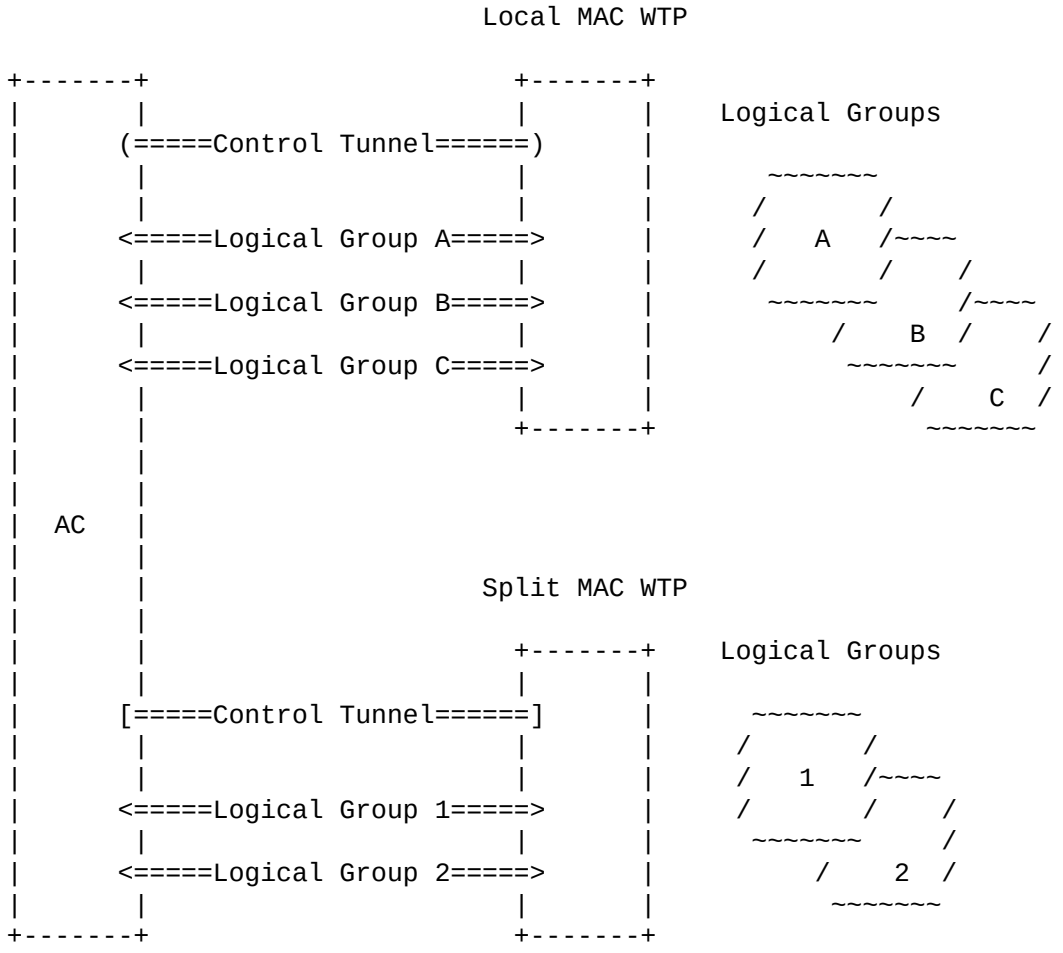


Figure 1

In Figure 1, WiCoP establishes and operates control tunnels and logical group tunnels between the AC and two types of WTPs. The control tunnels are used to transport WiCoP messages dealing with the configuration, monitoring, and management of WTPs as a physical whole. The logical group tunnels serve to separate traffic among each of the logical groups constituting a physical WTP.

2. Terminology

This document follows the terminologies of [RFC4118] and [RFC4564].

3. Protocol Overview

The Wireless LAN Control Protocol (WiCoP) focuses on enabling interoperability in shared infrastructure WLANs. It is designed for use with different wireless technologies. This document provides both the general operations of WiCoP and also specific use-cases with respect to IEEE 802.11-based systems.

The state machine for WiCoP is illustrated in Figure 2.

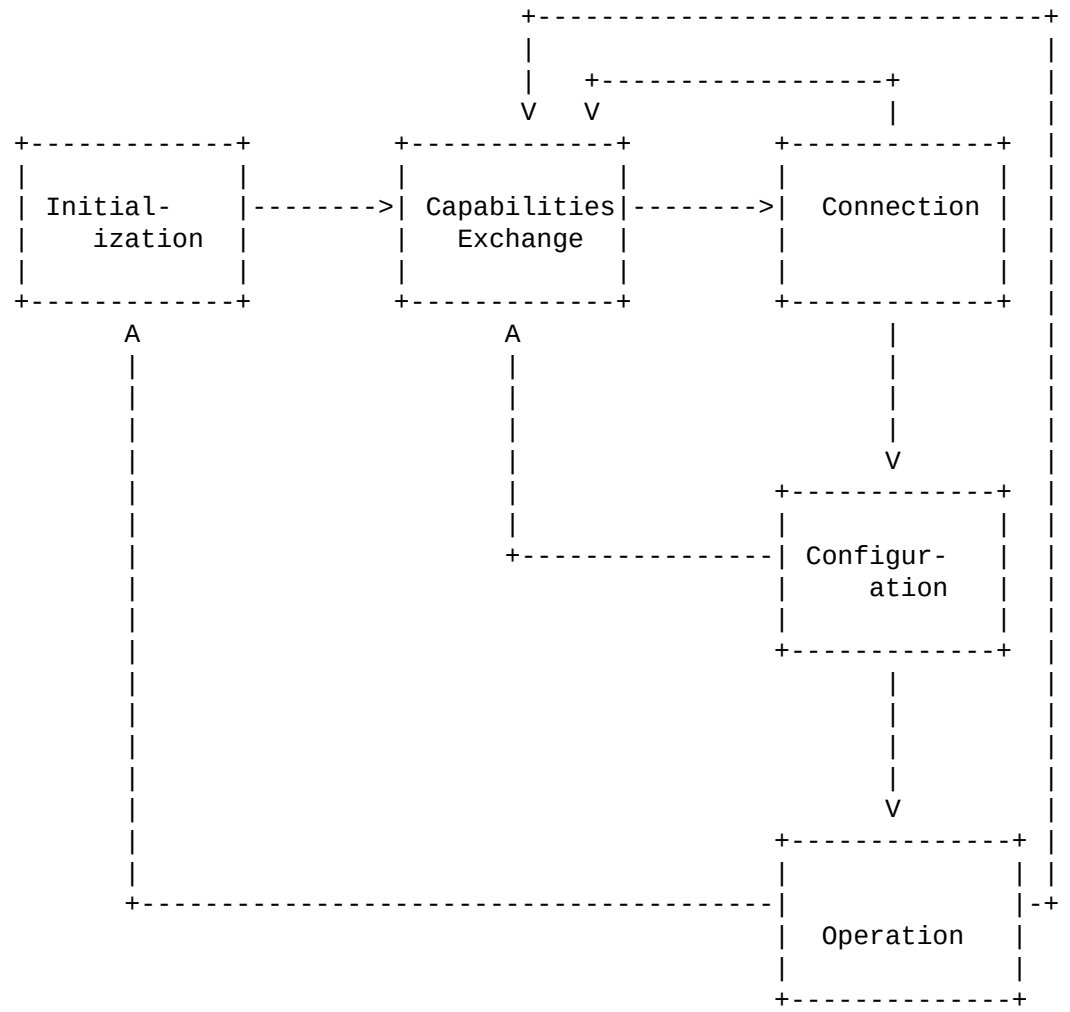


Figure 2

The Initialization state represents the initial states of WTPs and AC. A WTP or AC in this state powers on, clears internal registers, runs hardware self-tests, and resets network interfaces.

The Capabilities Exchange state represents initial protocol exchange between a WTP and AC. A WTP in this state determines possible ACs from which it can receive management services. An AC in this state determines the capabilities of the WTP and the WTP's compatibility with the management services it offers.

The Connection state represents the creation of a security infrastructure between a WTP and AC. This involves mutual authentication and the establishment of a secure connection between the WiCoP entities.

The Configuration state represents the exchange of long-term operational parameters and settings between a WTP and AC. A WTP in this state receives configuration information to allow it to operate consistently within the WLAN managed by the AC. An AC in this state provides configuration information to the WTP based on the WTP's capabilities and network policies.

The Operation state represents the active exchange of WiCoP monitoring and management messages. WTPs send regular status updates to and receive corresponding management instructions from the AC. This state also involves firmware and configuration updates arising from changes in network conditions and administrative policies.

4. WiCoP Format

WiCoP uses separate packets for control and data message transfer between the AC and WTPs. A common header is used for both types of packets in which a single-bit flag distinguishes between them. This section presents the packet formats for WiCoP packets.

4.1. WiCoP Header

Figure 3 illustrates the WiCoP common header for control and data packets.

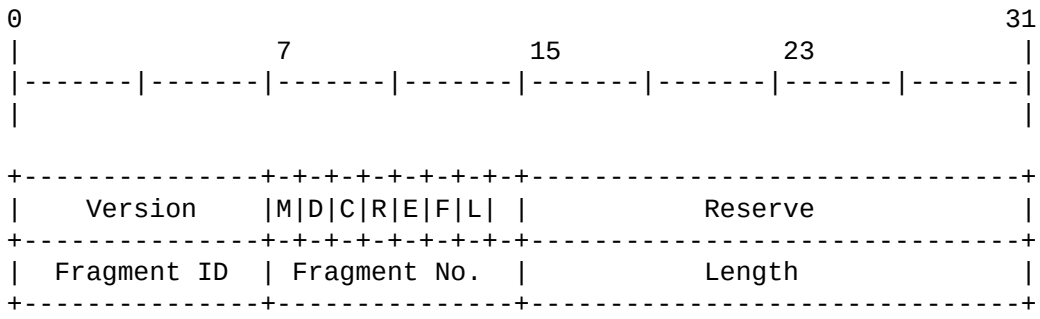


Figure 3

Version Field

This field indicates the protocol version.

'M' Field

The MAC-type field, 'M', distinguishes between Local MAC WTPs and Split MAC WTPs. It is used to efficiently realize interoperability between WTPs of the two different designs. A '0' value indicates WiCoP exchanges with a Split MAC WTP while a '1' value indicates WiCoP exchanges with a Local MAC WTP.

The presence of this classification bit in the WiCoP common header serves to expedite processing of WiCoP and WLAN traffic at the AC. With a single parsing of the WiCoP common header once, the AC will be able to determine the appropriate processing required for the particular WiCoP packet.

'D' Field

The differentiator field, 'D', is used to distinguish between WTP variants within a type of WTP design. The CAPWAP Architecture Taxonomy [RFC4118] illustrates that the Split MAC design allows encryption/decryption to be performed at either the WTP or the AC. The Architecture Taxonomy also indicates that the Local MAC design allows authentication to take place at either the WTP or the AC.

WiCoP acknowledges these major variants and accommodates them using the 'D' field in conjunction with the 'M' field. For a Split MAC WTP, the 'D' field is used to indicate location of encryption/decryption while for a Local MAC WTP, the 'D' field is used to indicate location of authentication. The following table highlights their usage.

'M'	'D'	Description
0	0	Split MAC WTP - Encryption/decryption is performed at WTP
0	1	Split MAC WTP - Encryption/decryption is performed at AC
1	0	Local MAC WTP - Authentication is performed by WTP
1	1	Local MAC WTP - Authentication is performed by AC

Similar to the 'M' field, the presence of this classification in the WiCoP common header helps expedite processing at the AC with a single parsing. By incorporating the classification bits in the WiCoP common header, where it is available for all packets of a session, the AC processing can be expedited. Alternatively, the AC would have to check each arriving packet against an internal register and consequently delay processing.

'C' Field

This field distinguishes between a WiCoP control and WiCoP data packet. Each type of information is tunneled separately across the WiCoP tunnel interfaces between WTPs and the AC. A '0' value for the 'C' field indicates a data packet, while a '1' value indicates a control packet.

The 'C' field is also used to assign WiCoP packets to distinct data and control tunnels between the AC and WTP. WiCoP also maintains logical groups in WLANs with the 'C' field.

'R' Field

The retransmission field, 'R', is used to differentiate between the first and subsequent transmissions of WiCoP packets. The 'R' field is used for critical WiCoP packets such as those relating to security key exchanges. A '0' value for the 'R' field indicates the first transmission of a WiCoP packet, while a '1' value indicates a retransmission.

'E' Field

The encryption field, 'E', is used to indicate if the WiCoP packet is encrypted between the AC and WTPs. The 'E' field is used for those WiCoP packets that are exchanged during initialization. A '0' value indicates the WiCoP packet is unencrypted, while a '1' value indicates the packet is encrypted.

'F' Field

The fragmentation field indicates if the packet is a fragment of a larger packet. A '0' value indicates a non-fragmented packet while a '1' value indicates a fragmented packet. The 'F', 'L', 'Fragment ID', and 'Fragment No.' fields are used together.

'L' Field

This field is used to indicate the last fragment of a larger packet. It is only valid when the 'F' field has a '1' value. A '0' value for the 'L' field indicates the last fragment of a larger packet while a '1' value indicates an intermediate fragment of a larger packet. The 'F', 'L', 'Fragment ID', and 'Fragment No.' fields are used together.

Fragment ID Field

The Fragment ID identifies the larger packet that has been fragmented. It is used to distinguish between fragments of different large packets. This field is valid only when the 'F' field has a '1' value. The 'F', 'L', 'Fragment ID', and 'Fragment No.' fields are used together.

Fragment No. Field

The fragment number field identifies the sequence of fragments of a larger packet. The value of the Fragment No. field is incremented for each fragment of a larger packet so as to show the order of fragments. This field is valid only when the 'F' field has a '1' value. The 'F', 'L', 'Fragment ID', and 'Fragment No.' fields are used together.

Length Field

This field specifies the length of the WiCoP payload following the header.

4.2. WiCoP Control Packet

The WiCoP control header follows the WiCoP common header. It is highlighted in Figure 5.

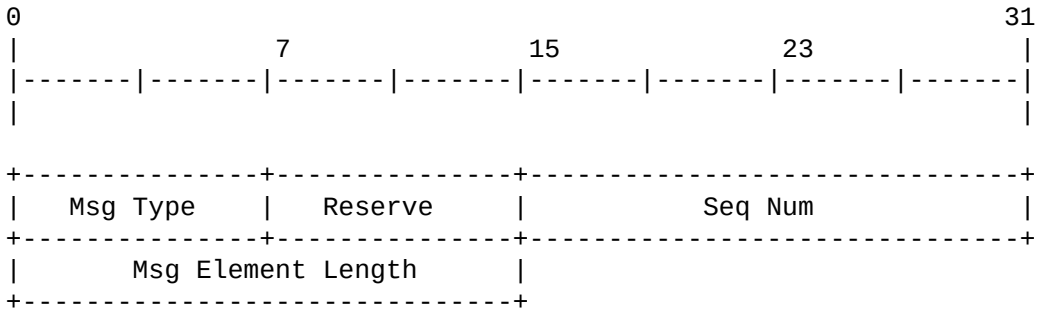


Figure 5

The control packet adds four additional fields to the common header. These are described below:

Msg Type Field

The message type field specifies the type of control message transported in the packet. The list of control messages is presented in Section 5.2.1.

Seq Num Field

The sequence number field is used to map WiCoP request and response sequences. The initiator of a WiCoP request message increments the Seq Num field for each new request message. The responder then uses these values of the Seq Num fields in its corresponding response messages.

Msg Element Length Field

This field specifies the length in bytes of the subsequent WiCoP control message element.

4.2.1. WiCoP Control Messages

The list of WiCoP control messages is shown below:

Message	Msg Type
Capabilities	1
Capabilities Response	2
Connection	3
Connection Response	4
Configuration Request	5
Configuration Response	6
Configuration Data	7
Configuration Data Response	8
Configuration Trigger	9
Configuration Trigger Response	10
Feedback	11
Feedback Response	12
Reset	13
Reset Response	14
Firmware Download	15
Firmware Download Response	16
Terminal Addition	17
Terminal Addition Response	18
Terminal Deletion	19
Terminal Deletion Response	20
Key Configuration	21
Key Configuration Response	22
Notification	23
Notification Response	24

4.2.2. WiCoP Control Message Elements

WiCoP control messages each include a control message header followed by one or more message elements. The message elements are shown in the following table:

Message Element	Type	Description
WTP-Info	1	Information regarding WTPs, such as manufacturer ID, MAC address, etc.
Cap-from-WTP	2	Quality-of-Service (QoS) abilities (WME-Wireless Multimedia Extension) and security abilities (IEEE 802.11i) are included
Conf-If-Data	3	Physical Layer (PHY) information for each wireless interface
Conf-WTP-Data	4	Information regarding logical groups on a per-logical group basis (e.g., per-virtual AP)
Cap-to-WTP	5	Setup data sent to WTPs by an AC on a per-logical group basis
QoS-Value	6	QoS setup (access categories)
Timer-Init-Value	7	Initial values of timers such as aging, echo interval, etc.
Terminal-Data	8	Information relevant to wireless terminals - Basic Service Set Identifier (BSSID), association ID, etc.
BSSID	9	BSSID, and terminal MAC address
Encryption-Data	10	Details of the security framework - cipher suit, operation mode, etc.
EAP-Frame	11	Extensible Authentication Protocol (EAP) frame
Statistics	12	Various statistics information - transmission attempts, Frame Check Sequence (FCS) errors, etc.
Interface-Error	13	Type of wireless interface failure
FROM-Error	14	Flash ROM Error information
QoS-Capability	15	Network congestion information

TFTP-Data	16	Firmware-related details
Result	17	Result of protocol operations - success or failure
OID	18	Simple Network Management Protocol (SNMP) Object Identifiers (OIDs)
GTK-Flag	19	Determines type of Group Temporal Key (GTK) - new or existing

Each message element comprises a number of information items that are detailed below. The length of each information item is specified in bytes.

WTP-Info:

Information included in the WTP-Info message element is provided on a per-WTP basis, i.e., each WTP exchanges one WTP-Info message element.

Item	Length	Syntax	Description
Manufacturer ID	8	DisplayString	Manufacturer ID
MAC Address	6	PhyAddress	WTP MAC Address
Firmware Version	8	DisplayString	Firmware version of WTP
Start Time	4	TimeTicks	Starting time of WTP (UNIX Time)

Cap-from-WTP:

Information included in the Cap-from-WTP message element is provided on a per-WTP basis, i.e., each WTP exchanges one Cap-from-WTP message element.

Item	Length	Syntax	Description
802.11e Cap Length	2	Integer	Length of 802.11e capabilities
802.11e Capabilities	Variable	OCTETString	802.11e capabilities of WTP. If WTP does not have such capabilities, this field is filled with '0'
802.11i Cap Length	2	Integer	Length of 802.11i capabilities
802.11i Capabilities	Variable	OCTETString	802.11i capabilities of WTP. If WTP does not have such capabilities,this field is filled with '0'
AuthType	2	OCTETString	Type of authentication mechanism used between WTPs and the AC

Conf-If-Data

The Conf-If-Data message element relates to the wireless interface. A WTP with many interfaces will include corresponding numbers of Conf-If-Data message elements within its control messages to the AC. Conf-If-Data message elements are indexed by the If ID information item.

Item	Length	Syntax	Description
If ID	1	Integer	Denotes identification of a wireless interface
Current Power	1	Integer	Current Power Level (’1’ = Max; ’2’ = 1/2; ’3’ = 1/4; ’4’ = 1/8
Radio Channel	1	Integer	Radio channel of operation
2Dot4Mode	1	Integer	Interface mode in 2.4GHz. (’1’ = IEEE 802.11b; ’2’ = IEEE 802.11g; ’3’ = Both)

Conf-WTP-Data

Configuration information is provided on the basis of logical groups such as virtual APs. There are multiple Conf-WTP-Data message elements to address the many logical groups within a WLAN managed by WiCoP. Conf-WTP-Data message elements are indexed by the BSSID information item.

Item	Length	Syntax	Description
BSSID	6	OCTETString	BSSID
ESSID	32	OCTETString	Extended Service Set Identifier (ESSID)
BSSID - TunnelID	32	OCTETString	Mapping for logical groups across BSSID and WiCoP tunnels
Beacon Period	1	Integer	Time interval between Beacon transmissions
DTIM Period	1	Integer	Delivery Traffic Indication Message (DTIM) period of Beacon transmissions

AnyRejectFlag	1	Integer	Flag indicating WTP rejection of any Probe Request within any SSID - (’1’ = Rejected; ’2’ = Not Rejected)
SSID Stealth Flag	1	Integer	Flag indicating inclusion of ESSID within Beacon Frames (’1’ = ESSID included; ’2’ = ESSID not included)
Operation Rate Set	2	Integer	Data rates supported by WTP for terminal being added using a 12-bit format for 1.1, 2.2, 3.55, 4.6, 5.9, 6.11, 7.12, 8.18, 9.24, 10.36, 11.48, and 12.54 Mbps
Encryption Type	1	Integer	Encryption Type - （’1’ = OFF; ’2’ = WEP40; ’3’ = WEP104; ’4’ = WEP128)
Encryption Key	16	OCTETString	Static Encryption Key

Cap-to-WTP:

Capabilities information is provided on the basis of logical groups such as virtual APs. So, there are multiple Cap-to-WTP message elements to address the many logical groups within a WLAN managed by WiCoP. Conf-to-WTP message elements are indexed by the BSSID information item. If logical groups are created by other means, their corresponding identifier is used as the index.

Item	Length	Syntax	Description
BSSID	6	OCTETString	BSSID
802.11e Cap Length	2	Integer	Length of 802.11e capabilities
802.11e Capabilities	Variable	OCTETString	802.11e capabilities of WTP. If WTP does not have such capabilities, this field is filled with '0'
802.11i Cap Length	2	Integer	Length of 802.11i capabilities
802.11i Capabilities	Variable	OCTETString	802.11i capabilities of WTP. If WTP does not have such capabilities, this field is filled with '0'

QoS-Value:

QoS parameters are assigned for each logical group to address their respective individual conditions and requirements. QoS-Value message elements are provided on a per-logical group basis. They are indexed by the BSSID information item. If logical groups are created by other means, their corresponding identifier is used as the index.

Item	Length	Syntax	Description
BSSID	6	OCTETString	BSSID
WTP AC_BE	2	Integer	AC Parameters Record AC_BE in WTP
WTP AC_BK	2	Integer	AC Parameters Record AC_BK in WTP
WTP AC_VI	2	Integer	AC Parameters Record AC_VI in WTP
WTP AC_VO	2	Integer	AC Parameters Record AC_VO in WTP
TE AC_BE	2	Integer	AC Parameters Record AC_BE in terminals
TE AC_BK	2	Integer	AC Parameters Record AC_BK in terminals
TE AC_VI	2	Integer	AC Parameters Record AC_VI in terminals
TE AC_VO	2	Integer	AC Parameters Record AC_VO in terminals

Timer-Init-Value:

WiCoP timers are used for the WTP as a whole. So, the Timer-Init-Value message element is provided on a per-WTP basis.

Item	Length	Syntax	Description
BSSID	6	OCTETString	BSSID
Response Timer	4	Integer	Initial value of Response Timer
Active Presence Timer	4	Integer	Initial value of Active Presence Timer
Feedback Interval Timer	4	Integer	Initial value of Feedback Interval Timer

Terminal-Data:

The Terminal-Data message element is applicable for both Local MAC and Split MAC WTP designs. In the case of Local MAC, Terminal-Data is sent from WTPs to the AC. In the case of Split MAC, Terminal-Data is sent from the AC to WTPs. So, the direction of usage depends on the type of WTP at which wireless terminal operations are performed. Some information items may be optional for use with specific WTP designs.

Item	Length	Syntax	Description
BSSID	6	PhyAddress	BSSID in which terminal is being added
MAC Address	6	PhyAddress	MAC address of terminal being added
Association ID	2	Integer	Association ID of terminal being added
Operation Rate Set	2	Integer	Data rates supported by WTP for terminal being added using a 12-bit format for 1.1, 2.2, 3.55, 4.6, 5.9, 6.11, 7.12, 8.18, 9.24, 10.36, 11.48, and 12.54 Mbps
Listen Period	2	Integer	Listen period

BSSID:

The BSSID message element is used to identify logical groups within a WLAN. WiCoP may be extended for other types of logical groups by simply including additional message elements.

Item	Length	Syntax	Description
BSSID	6	PhyAddress	BSSID in which terminal is being added
MAC Address	6	PhyAddress	MAC address of terminal being added

Encryption-Data:

The Encryption-Data message element contains information relevant for configuring security keys at WTPs. It is used in architectures in which the authentication and encryption points are located in distinct WLAN entities.

Item	Length	Syntax	Description
MAC Address	6	PhyAddress	MAC address of terminal
Operation	1	Integer	Operational Mode ('1' = Set Key; '2' = Delete Key)
Key Index	1	Integer	Key Index - valid when Operational Mode = Set Key
Key Flag	1	Integer	Key Flag ('1' = Unicast Key or PTK; '2' = Broadcast Key or GTK) - valid only when Operational Mode = Set Key
Cipher Suit	1	Integer	Encryption Type ('1' = WEP40; '2' = WEP104; '3' = WEP128; '4' = TKIP; '5' = AES) - valid only when Operational Mode = Set Key
Key	32	OCTETString	Key body - valid only when Operational Mode = Set Key

EAP-Frame:

The EAP-Frame message element is used to carry EAP frames used in the configuration and management of the WLAN.

Item	Length	Syntax	Description
MAC Address	6	PhyAddress	MAC address of terminal
EAP	Variable	OCTETString	EAP Frames

Statistics:

Statistics information covers all aspects of WTPs. As such, this message element is provided on a per-WTP basis. WiCoP messages containing the Statistics message element simultaneously serve as keepalive signals between WTPs and the AC.

Item	Length	Syntax	Description
OutOctet	4	Counter 32	Octet number of frame WTP transmits
Transmit Count	4	Counter 32	Total number of frames transmitted by WTP
Successful Transmit Count	4	Counter 32	Total number of ACKs received
ACK Failure Count	4	Counter 32	Total number of failed ACKs
InOctets	4	Counter 32	Octet number of frame WTP receives
Receive Count	4	Counter 32	Total number of frames received by WTP
Receive Discard	4	Counter 32	Total number of received frames that are discarded
Retransmissi on Count	4	Counter 32	Number of WTP retransmission attempts"

Duplicate Receive Count	4	Counter 32	Number of duplicate frames received by WTP
FCS Error Receive Count	4	Counter32	Number of frames received with FCS errors
Unknown Frame Receive Count	4	Counter 32	Number of unknown protocol frames received
Beacon Transmit Count	4	Counter 32	Number of transmitted Beacon frames
Probe Transmit Count	4	Counter 32	Number of transmitted Probe Response frames
Probe Receive Count	4	Counter 32	Number of received Probe Response frames
Decrypt CRC Error Count	4	Counter 32	Number of received frames that cannot decrypt

Interface-Error:

This message element is used to exchange information on error conditions related to the wireless interface.

Item	Length	Syntax	Description
Interface Index	1	Integer	Interface ID
Error Type	1	Integer	Type of error (’1’ = Unrecoverable; ’2’ = Recoverable)

FROM-Error:

The FROM-Error message element is used to exchange information on error conditions related to flash ROMs in WTPs or the AC.

Item	Length	Syntax	Description
FROM Index	1	Integer	FROM ID
Error Type	1	Integer	Type of error (’1’ = Unrecoverable; ’2’ = Recoverable)

QoS Capability:

The QoS-Capability message element is used to exchange information concerning the Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA) capabilities of WTPs.

Item	Length	Syntax	Description
EDCA	1	Integer	EDCA Capability (’1’ = Capable; ’2’ = Not capable)
HCCA	1	Integer	HCCA Capability (’1’ = Capable; ’2’ = Not capable)

TFTP-Data:

This message element is for firmware data from an AC to WTPs.

Item	Length	Syntax	Description
TFTP Data	Variable	OCTETString	Details of Trivial File Transfer Protocol (TFTP)

Result:

The Result message element is used in all WiCoP response messages to indicate the status of WiCoP request messages.

Item	Length	Syntax	Description
Result Code	1	Integer	'1' = OK; '2' = NG

OID:

The OID message element is used for general configuration information specified by OIDs.

Item	Length	Syntax	Description
Length	1	Integer	Length of OID String and OID Value
OID String	Variable	OCTETString	Object Identifier that is assigned according to Basic Encoding Rules (BER)
Value	Variable	OCTETString	Value

GTK-Flag:

The GTK-Flag message element is used to inform the WTP on the type of GTK used and correspondingly how the KeyMIC is to be computed.

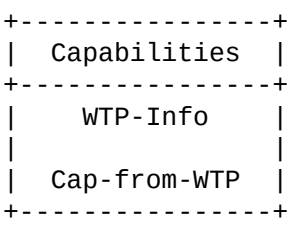
Item	Length	Syntax	Description
GTK Flag	1	Integer	Determines the type of GTK ('1' = New; '2' = Existing)

4.2.3. WiCoP Control Message Description

Message: Capabilities
Direction: WTP -> AC
Type: Request

Description: WTPs send a Capabilities message upon transitioning from the Initialization state to the Capabilities Exchange state. The message serves to discover and identify the controlling AC of the WLAN and to provide it with identification and capabilities information. In the IEEE 802.11 use-case, the Capabilities message also specifies the WTP's IEEE 802.11e and IEEE 802.11i features.

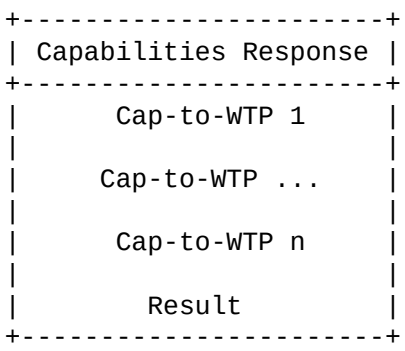
TLV: The Capabilities message includes message elements of types 1 and 2.



Message: Capabilities Response
Direction: AC -> WTP
Type: Response

Description: This message is sent by an AC after examining the compatibility of the WTP and its capabilities. The compatibility is with respect to the MAC architecture that can be supported by the AC. If the WTP is determined to be compatible, the Capabilities Response message also contains information on the capabilities of the AC.

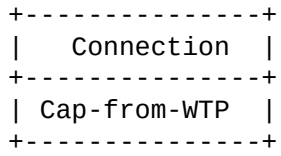
TLV: The Capabilities Response message includes message elements of types 5 and 17. The Cap-to-WTP message elements are distinguished based on BSSIDs to represent different logical groups.



Message: Connection
Direction: WTP -> AC
Type: Request

Description: The Connection message initiates the mutual security association between an AC and WTPs. This message carries the first message of the chosen security protocol. The specific security mechanism for the authentication is out of scope of the WiCoP specifications.

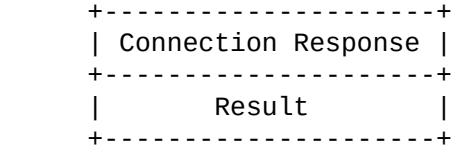
TLV: The Connection message includes message elements of type 2.



Message: Connection Response
Direction: AC -> WTP
Type: Response

Description: After completion of the security protocol exchange, this message indicates the result of the WTP-AC security association. If successful, it also represents the admission of the WTP into the WLAN.

TLV: Type 17 message element is included.



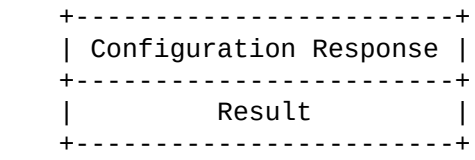
Message: Configuration Request
Direction: WTP -> AC
Type: Request

Description: This message starts the Configuration state for the WTP. It is a request for configuration information from the WTPs to the AC.

Message: Configuration Response
Direction: AC -> WTP
Type: Response

Description: This is an acknowledgement for the Configuration Request message.

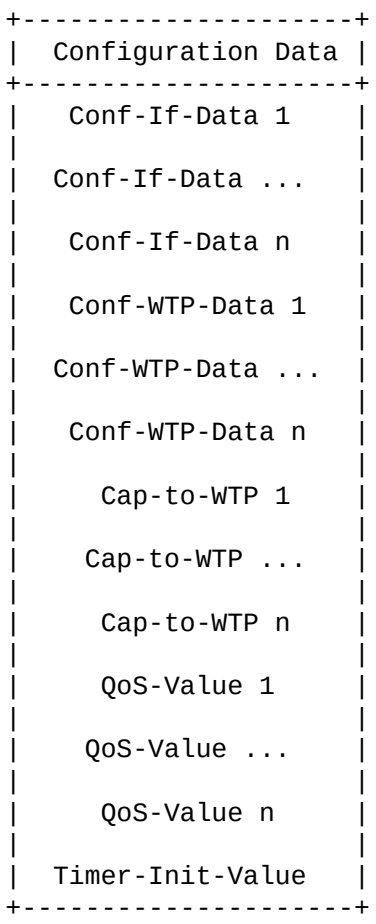
TLV: Type 17 message element is included.



Message: Configuration Data
Direction: AC -> WTP
Type: Request

Description: Configuration information including operational parameters, QoS settings, and timer values is sent using the Configuration Data message. This message is also used for configuration updates in the Operation state of WiCoP.

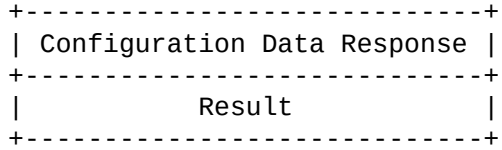
TLV: This message includes message elements of types 3, 4, 5, 6, and 7. The Conf-WTP-Data and QoS-Value message elements are identified by BSSIDs to denote logical groups, while the Conf-If-Data message elements are identified by If-IDs to denote multiple wireless radios.



Message: Configuration Data Response
Direction: WTP -> AC
Type: Response

Description: This is an acknowledgement for the Configuration Data message.

TLV: Type 17 message element is included.



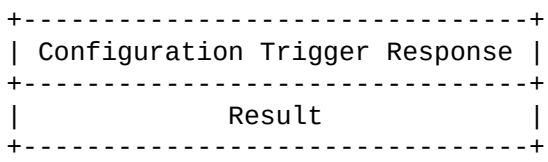
Message: Configuration Trigger
Direction: AC -> WTP
Type: Request

Description: This message is used to trigger the activation of the configuration information sent in earlier Configuration messages.

Message: Configuration Trigger Response
Direction: WTP -> AC
Type: Response

Description: This is an acknowledgement of the Configuration Trigger. This response message is sent before activation of the configuration information.

TLV: Message elements of type 17 are included.



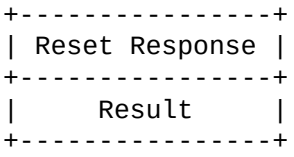
Message: Reset
Direction: AC -> WTP
Type: Request

Description: This message from the AC instructs the WTP to clear registers and revert to initial conditions.

Message: Reset Response
Direction: WTP -> AC
Type: Response

Description: This is an acknowledgement for the Reset message to the AC.

TLV: Message elements of type 17 are included.



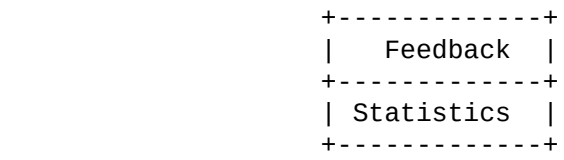
Message: Feedback
Direction: WTP <-> AC
Type: Request

Description:

WTP: The Feedback message is used to send regular statistics information to the AC. It also serves as a keepalive indicator used to update the Active Presence Timer maintained by the AC.

AC: The Feedback message is used to determine the active state of WTPs.

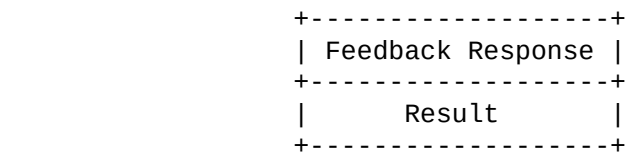
TLV: This message includes message elements of type 12.



Message: Feedback Response
Direction: WTP <-> AC
Type: Response

Description: This is an acknowledgement for Feedback messages.

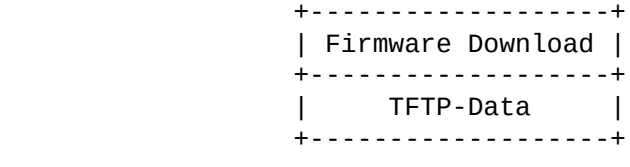
TLV: Message elements of type 17 are included.



Message: Firmware Download
Direction: AC -> WTP
Type: Request

Description: This message is used to instruct WTPs to update their firmware. The message element contains information regarding the new firmware.

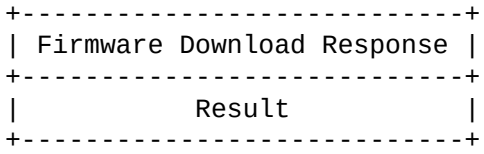
TLV: Message elements of type 16 are included.



Message: Firmware Download Response
Direction: WTP -> AC
Type: Request Response

Description: This is an acknowledgement for the Firmware Download message.

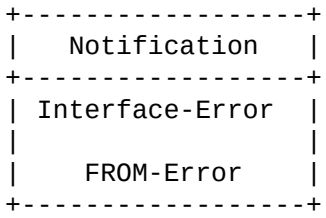
TLV: Message elements of type 17 are included.



Message: Notification
Direction: WTP <-> AC
Type: Request

Description: This message is used to indicate non-periodic events. It may be sent by either WTPs or the AC. Notification messages indicate failures, non-periodic changes, etc.

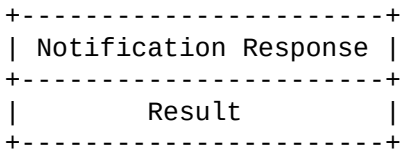
TLV: Message elements of types 13 and 14 are included.



Message: Notification Response
Direction: WTP <-> AC
Type: Response

Description: This is an acknowledgement for the Notification message. It may be followed by Configuration messages to rectify errors.

TLV: Message elements of type 17 are included.



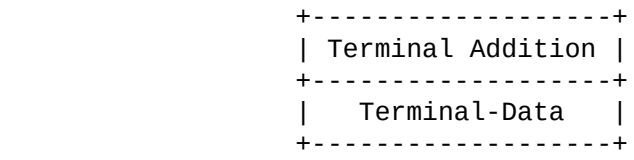
Message: Terminal Addition
Direction: WTP <-> AC
Type: Request

Description: This message may be sent from WTPs or the AC, depending on the WTP type in consideration. In both cases, it is sent in response to an IEEE 802.11 association frame.

For Split MAC WTPs, Terminal Addition is sent from the AC to the WTPs and includes information on the wireless terminal relevant to the WTP.

For Local MAC WTPs, Terminal Addition is sent from a WTP to the AC and contains information on the wireless terminal relevant to the AC.

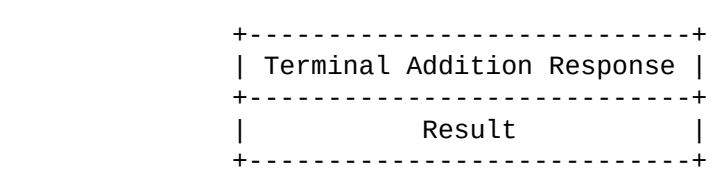
TLV: Message elements of type 8 are included.



Message: Terminal Addition Response
Direction: WTP <-> AC
Type: Response

Description: This is an acknowledgement sent from either WTPs or the AC, depending on the WTP type in consideration.

TLV: Message elements of type 17 are included.



Message: Terminal Deletion
Direction: WTP <-> AC
Type: Request

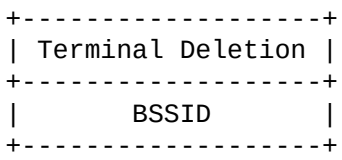
Description: This message is sent in response to a disconnection of a wireless terminal. It can be sent from WTPs or the AC. In both cases, Terminal Deletion instructs the recipient to remove any state information relating to the specific wireless terminal. The message

is sent in response to an IEEE 802.11 disassociation frame, IEEE 802.11 deauthentication frame, or due to the expiration of the Active Presence Timer.

For Split MAC WTPs, Terminal Deletion is sent from the AC to the WTPs.

For Local MAC WTPs, Terminal Deletion is sent from the WTPs to the AC.

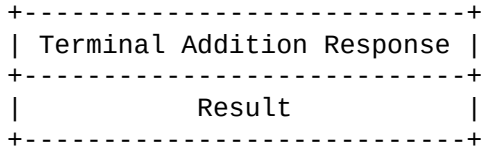
TLV: Message elements of type 9 are included.



Message: Terminal Deletion Response
Direction: WTP <-> AC
Type: Response

Description: This is an acknowledgement sent from either WTPs or the AC, depending on the WiCoP interface.

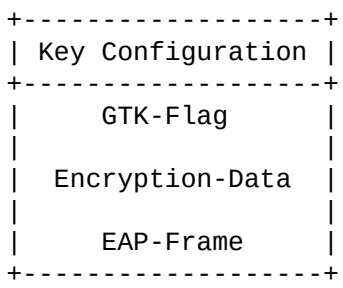
TLV: Message elements of type 17 are included.



Message: Key Configuration
Direction: AC -> WTP
Type: Request

Description: This message is used when authentication and encryption points are located in distinct WLAN entities. WiCoP uses it in cases where 'M' = 0 and 'D' = 0 or where 'M' = 1 and 'D' = 1. It is used to configure security key information from the AC to the WTPs.

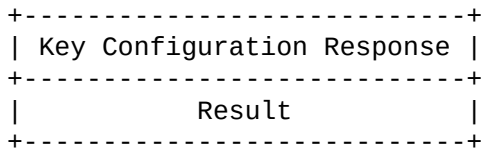
TLV: The following message elements are included for Key Configuration.



Message: Key Configuration Response
Direction: WTP -> AC
Type: Response

Description: This is an acknowledgement for the Key Configuration message.

TLV: Message elements of type 17 are included.



4.3. WiCoP Data Packet

WiCoP data packets include the WiCoP common header followed by a payload. Data packets are used to distinguish traffic from control when both control and data paths are identical. Such a scenario would involve data traffic of the WTPs traversing the AC. However, given the diversity of large-scale WLAN deployments, there are scenarios in which data and control paths are distinct. WiCoP can be used in both cases.

The WiCoP data packet format is illustrated below in Figure 7, together with the WiCoP common header.

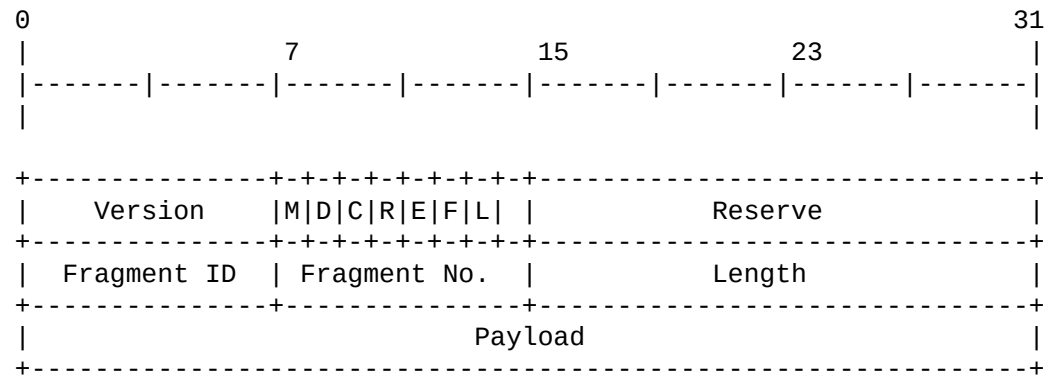


Figure 7

4.4. WiCoP Timers

WiCoP uses a number of timers to determine WLAN status and maintain system performance. Timers are maintained by all WiCoP entities.

4.4.1. Active Presence Timer

The Active Presence Timer is used by each WiCoP entity -- AC and WTPs -- to verify the presence of each other. The absence of a reply to the Feedback message within the expiration of the Active Presence Timer indicates the corresponding entity is inactive. Contingency operations such as reset are used in this case. The value of the Active Presence Timer ranges from 10 to 300 seconds with a default value of 30 seconds.

4.4.2. Feedback Interval

Feedback messages are periodic with the frequency defined by the Feedback Interval. The interval is set during WTP configuration. It has a value ranging from 1 to 100 seconds and a default value of 10 seconds.

The Feedback Interval timer sets the periodicity of WLAN system audits. So with this timer, the WLAN controller receives regular information on the state of the WLAN and all its WTPs.

4.4.3. Response Timer

This is a general-purpose timer used to limit the elapsed time between transmission of a request message and receipt of a corresponding response message. The value of this timer ranges from 1 to 3 seconds with a default value of 1 second.

4.4.4. Wireless Connectivity Timer

This timer triggers any changes in wireless connectivity. WiCoP uses this timer to send Notification and other messages relating to wireless conditions. It is also used to trigger the disconnection of mobile terminals without disassociation. The value of the Wireless Connectivity Timer ranges from 1 minute to 86,400 minutes with a default value of 10 minutes.

5. WiCoP Processes

The processes of the Wireless LAN Control Protocol are described in this section with respect to the operational state in which they occur.

5.1. Initialization

The Initialization state represents the initial conditions of WiCoP entities. WTPs and ACs in this state are powered on, run hardware self-check tests, and reset network interfaces.

State transition: Initialization -> Capabilities Exchange
WTP: Automatically upon detecting an active network interface
AC: Upon receiving a Capabilities message from a WTP

5.2. Capabilities Exchange

The Capabilities Exchange state allows WTPs to first find an AC and then to exchange capabilities information with it.

WiCoP is designed to control WLANs with both Local MAC and Split MAC WTPs. The differences in their respective functional characteristics are determined in this state.

The WTP first broadcasts a Capabilities message as soon as it transitions from its Initialization state. The Capabilities message serves to discover ACs and contains information on its identity and capabilities.

The AC receiving the Capabilities message transitions from its Initialization state. It examines compatibility with respect to the WTP type, its capabilities, and responds with an appropriate Capabilities Response message.

The WTP continues to send Capabilities messages at an interval specified by the Response Timer until it receives a Capabilities Response message from an AC.

The AC maintains a count of Capabilities messages received from a given WTP, which it uses to ignore WTPs after a limit. This is to ensure that rogue WTPs that are not compatible with the AC do not repeatedly attempt connections. The limit of connection attempts is 3 within 60 seconds.

State transition: Capabilities Exchange -> Connection

WTP: Upon receiving a positive Capabilities Response message from an AC

AC: Upon receiving a Connection Request message from a WTP

5.3. Connection

The Connection state involves establishing a security infrastructure between WTPs and an AC.

The WTP sends a Connection message to trigger the authentication and security mechanism, i.e., this message initiates an IPsec security association.

The AC sends a positive Connection Response message after establishment of the security association or a negative Connection Response message if an error occurs. The AC also monitors the receipt of WiCoP control messages to prevent replay attacks.

The security association between an AC and WTPs covers mutual authentication and also protection for integrity, confidentiality, and modification protection for subsequent traffic exchanges.

In order to avoid forceful disconnections of legitimate WTPs after a successful Connection, the AC ignores Capabilities messages received with a previously registered WTP identification.

State transition: Connection -> Configuration

WTP: Upon successful establishment of security infrastructure marked by sending of a Configuration Request message

AC: Upon receiving Configuration Request message from a WTP after successful establishment of security infrastructure

State transition: Connection -> Capabilities Exchange

WTP: Upon expiry of the WTP Response Timer before receipt of a positive Connection Response message from an AC or upon receipt of a negative Connection Response message

AC: Upon expiry of AC Response Timer before receipt of Configuration Request message from WTP

5.4. Configuration

The Configuration state is one in which relatively long-term operational parameters, such as those for identification and logical groups, are exchanged. These parameters are based on previously exchanged capabilities information and network policies.

The WTP sends a Configuration Request message to the AC.

The AC first acknowledges the WTP's Configuration Request, after which it sends appropriate configuration information in subsequent Configuration Data messages. WiCoP includes MIB objectives as message elements in some Configuration Data messages so as to simplify WTP configuration.

The WTP acknowledges Configuration Data messages individually or en bloc with Configuration Data Response messages. The Response Timer is maintained at both WTP and AC to track the exchanges.

The AC also establishes relevant processing schedules according to the WTP's architecture design. For example, for Split MAC WTPs, the AC arranges its processing schedule to parse IEEE 802.11 control and management messages while for Local MAC WTPs, the AC arranges schedules processing so as to bypass parsing of IEEE 802.11 management messages.

The AC sends a Configure Trigger message after sending all relevant configuration information to the WTP.

The WTP acknowledges a Configure Trigger message with a Configure Trigger Response message before activating the previously exchanged configuration parameters.

In order to avoid forceful disconnections of legitimate WTPs after successful Configuration, the AC ignores Capabilities messages received with a previously registered WTP identification.

State transition: Configuration -> Operation

WTP: After receiving final Configuration Data message from the AC marked by receipt of a Configure Trigger message from the AC

AC: Upon receiving acknowledgement for Configure Trigger message marked by receipt of a Configure Trigger Response message from WTP

State transition: Configuration -> Capabilities Exchange

WTP: Upon expiry of the WTP Response Timer before receipt of a Configure Trigger message from the AC

AC: Upon expiry of the AC Response Timer before receipt of Configure Data Response message or Configure Trigger Response message

The following describes major configuration aspects of WiCoP.

5.4.1. Logical Groups

Configuration Data messages are used to establish logical groups in the WLAN and also to separate traffic among them. The logical groups are established based on network administrative policies and other external considerations. In the IEEE 802.11 use-case, logical groups are established with BSSID-based virtual APs and are separated over the WiCoP interface using tunnels.

The AC assigns particular BSSIDs of the WTP to specific VLAN tunnels. This assignment is specified to the WTP using the BSSID-TunnelID parameter in the Configuration Data message. The logical group mapping therefore works across the wireless and WiCoP interfaces.

The WTP then identifies the specified BSSID and VLAN tunnel as corresponding to one logical group. It creates internal state such that traffic belonging to the logical group is kept distinct from that of other logical groups.

The AC and WTP also use distinct VLAN tunnels for data and control traffic. The 'C' field in the WiCoP header is used to distinguish and assign WiCoP packets to particular data and control VLAN tunnels.

5.4.2. Resource Control

The AC sends QoS information using QoS-Value message elements in Configuration Data messages. The QoS-Value message element contains values for EDCA and HCCA parameters. This information is specified for each of the logical groups. In the IEEE 802.11 use-case, QoS-Value message elements are specified for each BSSID.

The WTP configures QoS parameters locally and also forwards relevant settings to wireless terminals in appropriate encapsulations. In the IEEE 802.11 use-case, QoS parameters are sent to wireless terminals in corresponding Beacon or Probe Response frames.

5.5. Operation

This is the active operation state of the WLAN in which short-term dynamics are examined.

The WTP begins operations according to the operational parameters exchanged in the previous Configuration state.

The AC monitors WTPs according to network administrative policies and configurations.

In order to avoid forceful disconnections of legitimate WTPs after successful Operation setup, the AC ignores Capabilities messages received with a previously registered WTP identification.

State transition: Operation -> Capabilities Exchange
WTP: Upon expiry of the WTP Active Presence Timer before receipt of a Feedback Response message from the AC
AC: Upon expiry of the AC Active Presence Timer before receipt of a Feedback message from the WTP

State transition: Operation -> Initialization
WTP: Upon receipt of a Reset message from an AC
AC: Upon receipt of a Reset Response message from a WTP

The following describes major operation aspects of WiCoP.

5.5.1. Updates

The dynamic nature of WLAN systems requires regular updates to network operations.

The AC sends additional configuration information in the Configuration Data messages. This is applicable to establishment of new logical groups, changes to existing logical groups, changes in QoS settings, etc. Configuration information is followed by a Configure Trigger message.

The WTP sends a Configure Trigger Response before activating the additional configuration information.

Configuration updates can be used to clear statistics information by reflecting initial values.

An extreme case of a configuration update involves use of the Reset message from the AC, which instructs the WTP to revert to initial conditions. The WTP replies with a Reset Response message before reverting to its initial state.

5.5.2. Feedback and Statistics

The Operation state also sees regular feedback being sent by WTPs to the AC.

The WTP sends Feedback messages to indicate various statistics and congestion condition information. Feedback also includes information on the state of the WTP and wireless medium such as queue levels and channel interference. Feedback messages are sent with a frequency defined by the Feedback Interval. In addition to statistics, the Feedback message also serves as a WTP keepalive indicator to the AC. Feedback messages combine statistics information together with WTP status information.

The AC monitors Feedback messages for their statistics value and implicit indication of WTP activity. The AC also tracks the state of congestion at wireless terminals and WTPs. This information enables the AC to adapt its downstream transmissions, such as scheduling transmission away from congested WTPs, so as to relieve congestion.

The AC additionally uses the Feedback message to randomly determine the active state of WTPs. An active WTP replies with a corresponding Feedback Response message.

5.5.3. Non-Periodic Events

The WTP and AC use the Notification message for non-periodic events. They send Notification messages to indicate error conditions or drastic changes in congestion state.

The recipient of the Notification message acknowledges with a Notification Response message. The response may contain information on rectifying the error or may simply be an acknowledgement of the Notification.

5.5.4. Firmware Trigger

The AC sends a Firmware Download message to update firmware at WTPs. The Firmware Download message contains TFTP information, which the WTP uses to refresh its firmware. This is used when a new version of firmware is available for the WTPs.

The WTP acknowledges new firmware with a Firmware Download Response message after which it is activated.

5.5.5. Wireless Terminal Management

The Operation state of WiCoP also involves configuration of WTPs and the AC with wireless terminal-specific information.

Here the Terminal Addition message is used in response to a new wireless terminal entering the WLAN. This message may be sent by either the WTPs or the AC, depending on the WiCoP interface being used. The recipient of this message replies with the Terminal Addition Response message.

The Terminal Deletion message is used when a wireless terminal leaves the WLAN. This is used to delete state information that was maintained by either the WTPs or the AC. It is acknowledged with the Terminal Deletion Response message.

Figure 8 below illustrates the exchange of Terminal Addition and Terminal Deletion messages for both Local-MAC- and Split-MAC-based WiCoP interfaces.

Here the WiCoP Terminal Addition message is triggered as a response to an IEEE 802.11 Association message. In the case of Local MAC architecture, the WTP sends the message to the AC. However, in the Split MAC architecture, Terminal Addition is sent from an AC to the WTP.

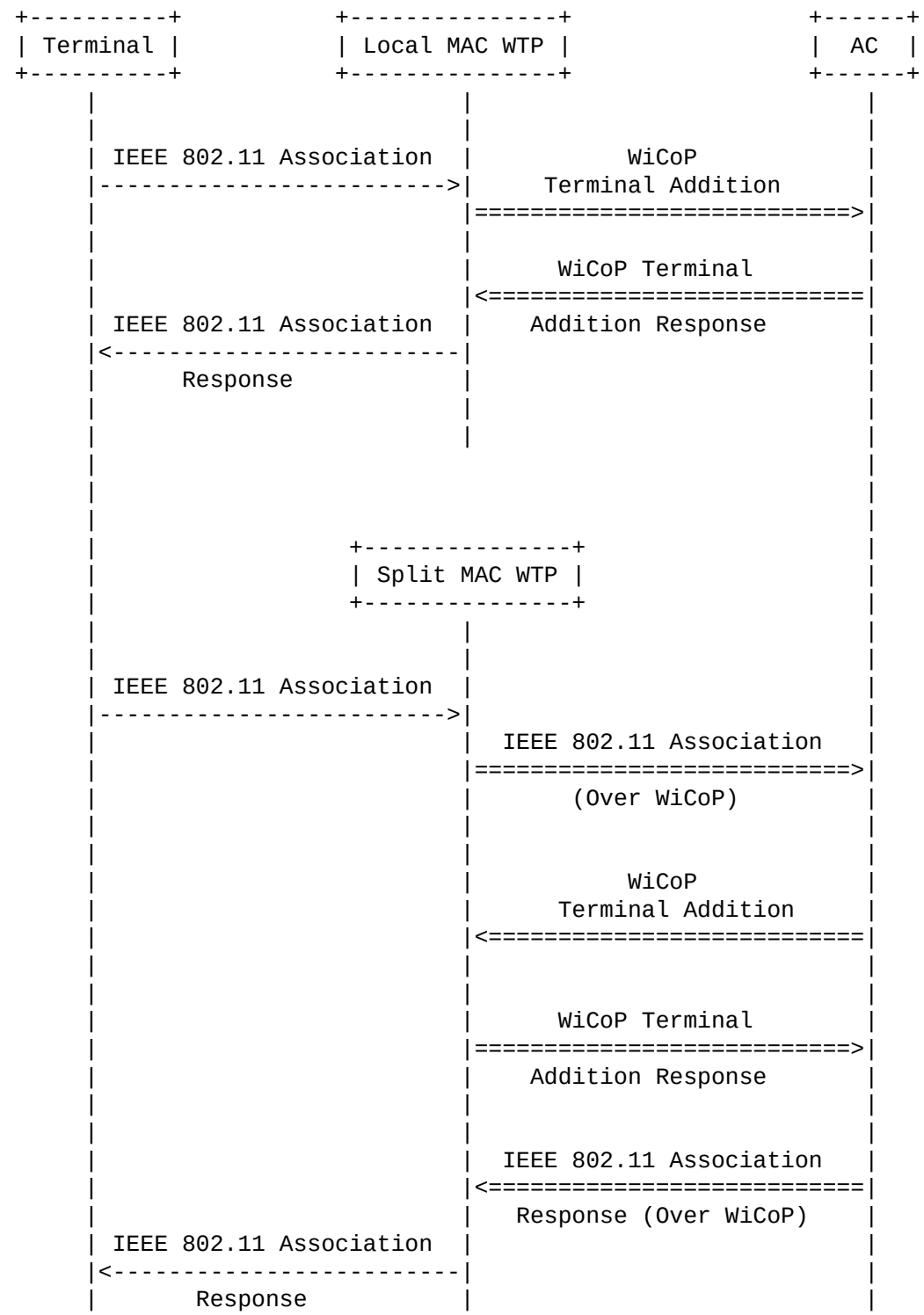

Terminal
Local MAC WTP
AC
IEEE 802.11 Association
WiCoP
Terminal Addition
WiCoP Terminal
Addition Response
IEEE 802.11 Association
Response
Split MAC WTP
IEEE 802.11 Association
IEEE 802.11 Association
(Over WiCoP)
WiCoP
Terminal Addition
WiCoP Terminal
Addition Response
IEEE 802.11 Association
Response (Over WiCoP)
IEEE 802.11 Association
Response

Figure 8

5.5.6. Key Configuration

One of the differences between Split MAC and Local MAC WTPs is the location of the over-the-air encryption. Some Split MAC and Local MAC WTPs perform encryption locally while others leave it to the AC. WiCoP accommodates these differences by enabling security key configuration in those cases where encryption is performed at the WTP. The encryption setup process is therefore contingent on the WiCoP protocol interface.

When dynamic WEP is used, the WiCoP Key Configuration message is used to notify WTPs of encryption keys for each associated wireless terminal. Here, the EAP over LAN (EAPoL) Key frame is encapsulated in the Key Configuration message and sent to a WTP. Upon receiving the Key Configuration message, the WTP sets the encryption key in its local security table, decapsulates the EAPOL Key frame and forwards it to the wireless terminal. This is illustrated in Figure 9.

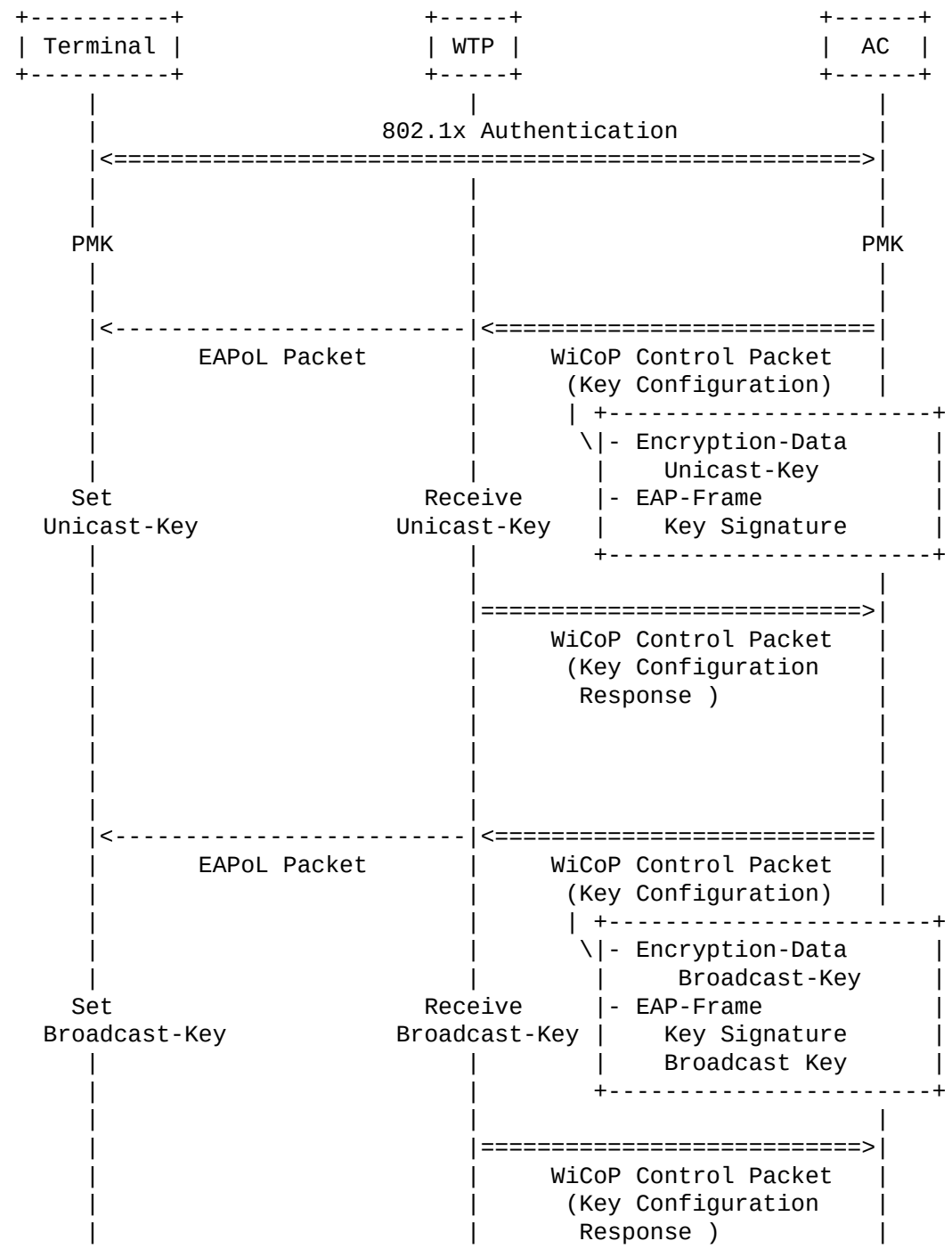

Terminal
WTP
AC
802.1x Authentication
PMK
PMK
EAPoL Packet
WiCoP Control Packet
(Key Configuration)
Encryption-Data
Unicast-Key
EAP-Frame
Key Signature
Set
Unicast-Key
Receive
Unicast-Key
WiCoP Control Packet
(Key Configuration
Response)
EAPoL Packet
WiCoP Control Packet
(Key Configuration)
Encryption-Data
Broadcast-Key
Set
Broadcast-Key
Receive
Broadcast-Key
EAP-Frame
Key Signature
Broadcast Key
WiCoP Control Packet
(Key Configuration
Response)

Figure 9

When WPA or IEEE 802.11i is used in WLAN architectures in which the authenticator is located at the AC and encryption points at WTPs, the exchanges of the 4-way handshake are managed distinctly. This is because the AC is no longer in a position to calculate the KeyMIC as it is not aware of the KeyRSC sequence counter. So here, a WiCoP Key Configuration message is used to transport the 3rd message of the 4-way handshake -- containing the EAPoL-Key -- with unassigned KeyRSC and KeyMIC fields. When the WTP receives the WiCoP Key Configuration message, it first assigns the sequence number value to the KeyRSC field. Then, the WTP calculates the KeyMIC value using the PTK and KeyRSC. So, the WiCoP Key Configuration message allows the KeyMIC to be calculated at the WTPs instead of the AC. The GTK-Flag message element is used to determine how the KeyMIC is calculated -- in case of a new GTK, KeyMIC is computed with a KeyRSC value of 0 and in case of an existing GTK, KeyMIC is computed with a KeyRSC value corresponding to the actual counter.

Figure 10 illustrates this case where the WiCoP common header is either 'M' = 0 and 'D' = 0 or 'M' = 1 and 'D' = 1.

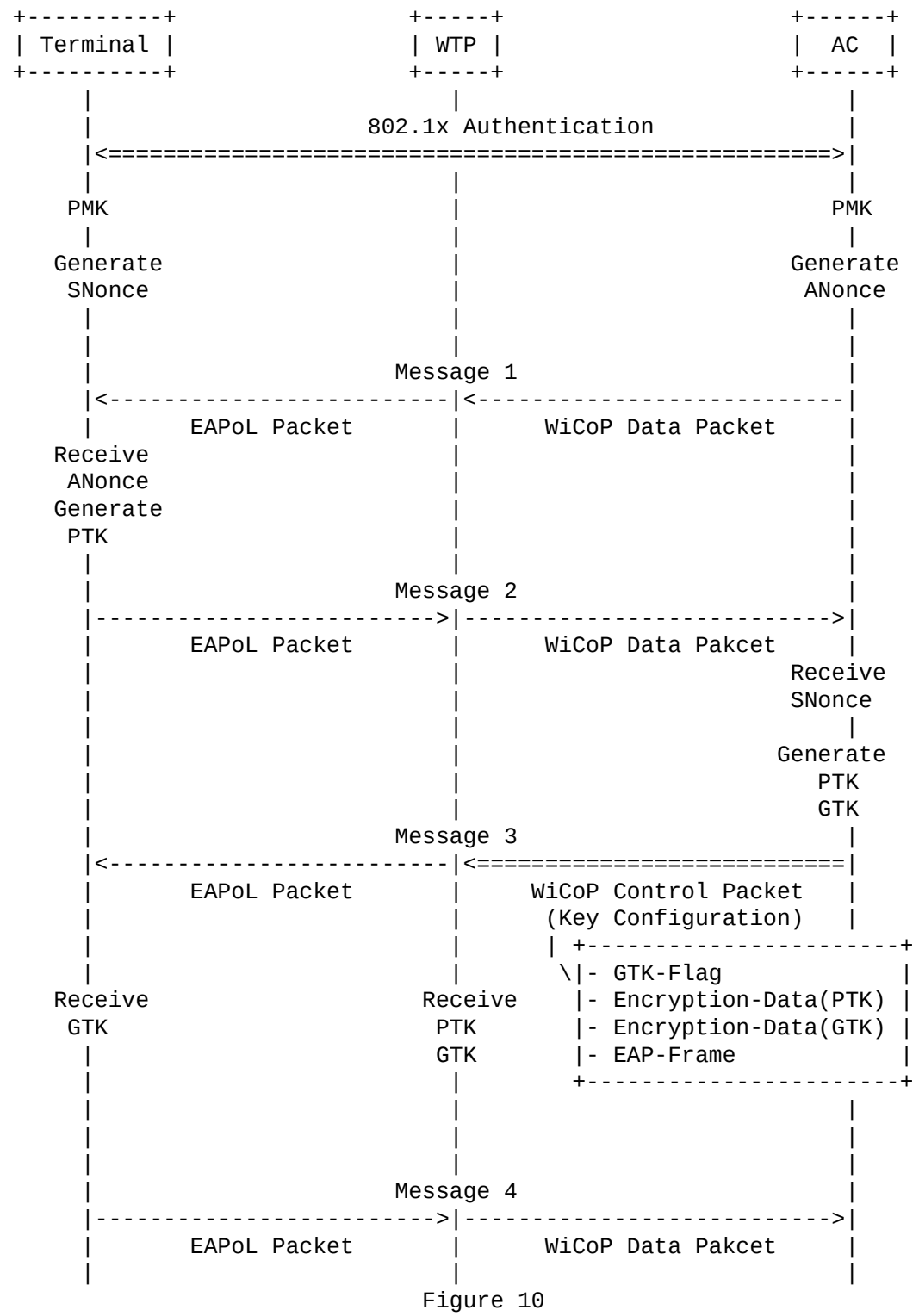

Terminal
WTP
AC
802.1x Authentication
PMK
Generate SNonce
PMK
Generate ANonce
Message 1
EAPoL Packet
WiCoP Data Packet
Receive ANonce
Generate PTK
Message 2
EAPoL Packet
WiCoP Data Pakcet
Receive SNonce
Generate PTK GTK
Message 3
EAPoL Packet
WiCoP Control Packet (Key Configuration)
GTK-Flag
Encryption-Data(PTK)
Encryption-Data(GTK)
EAP-Frame
Receive GTK
Receive PTK GTK
Message 4
EAPoL Packet
WiCoP Data Pakcet

Figure 10

The 1st, 2nd, and 4th messages of the 4-way handshake are transported in WiCoP data packets that are assigned priorities similar to that of WiCoP control packets.

Similarly, for the group key handshake in WPA and IEEE 802.11i, the 1st message of the handshake is transported using the WiCoP Key Configuration message with unassigned KeyRSC. The WTP again assigns the sequence number value to the KeyRSC and then calculates the KeyMIC. The 2nd message of the handshake however is transported in WiCoP data packets with priorities similar to that of WiCoP control packets. This is illustrated in Figure 11.

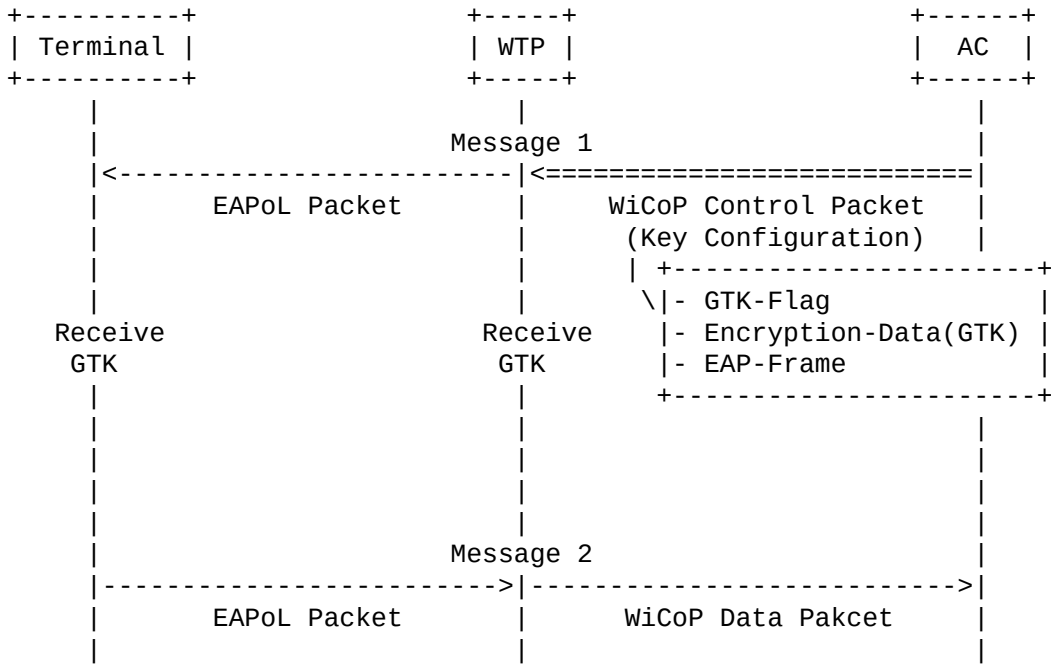


Figure 11

The Key Configuration Response message is used by the WTP to notify the AC of the encryption setup process.

6. WiCoP Performance

WiCoP is an efficient protocol. This section illustrates various examples of its efficiency.

6.1. Operational Efficiency

The fact that WiCoP requires a single operation to distinguish and manage WTPs of different designs makes it operationally efficient. Because WiCoP assigns dedicated classification bits in the common header, an AC needs to parse incoming packets only once to determine the particular manner in which it is to be processed. Without the dedicated classifications in the common header, an AC would have to perform a lookup after parsing every incoming packet, which would result in delaying processing. The scale and sensitivity of large-scale deployments require that WLAN control protocols be efficient in operation.

6.2. Semantic Efficiency

In certain cases, WiCoP combines utilities in a single operation. One particular case is that of statistics and activity feedback. Here, WTPs regularly send a single Feedback message containing statistics and other state information, which also acts as an implicit keepalive mechanism. This helps to reduce the number of message exchanges and also simplifies protocol implementation. Similarly, the Capabilities messages serve the purpose of finding ACs as well as informing them of WTP capabilities and design.

7. Summary and Conclusion

The Wireless LAN Control Protocol presents a solution for managing large-scale WLANs with diverse elements. It addresses the challenges presented in the CAPWAP Problem Statement [RFC3990] and realizes the requirements of the CAPWAP Objectives [RFC4564].

WiCoP enables integral control of Split MAC and Local MAC WTPs by defining appropriate differentiators within the protocol message exchanges and processes. It addresses architecture designs in which the authenticator and encryption points are located on distinct entities. In doing so, WiCoP realizes the interoperability objective and its benefits.

WiCoP also addresses shared WLAN deployments by configuring and managing WTPs on a logical group basis. It is further provisioned to separate control and data traffic within WLANs. So, the protocol addresses the objectives of logical groups and traffic separation.

Overall, the specifications presented in this document allow for an effective WLAN control and provisioning protocol.

8. Security Considerations

Illegitimate WTPs and ACs pose a significant threat to WLAN security. This can be mitigated by requiring all WiCoP entities to be mutually authenticated before initiating critical protocol exchanges. WiCoP includes a trigger for a suitable authentication mechanism. This is to accommodate a different security mechanism that may be used between WTPs and the AC, depending on the nature of the deployment.

In extension to mutual authentication, the subsequent exchange of protocol information between WTPs and the AC need to be protected. The exchanges have to be protected against alterations of any sort and Denial-of-Service (DoS) attacks. Also, the information should not be accessible to any third party. Encryption of protocol exchanges is therefore necessary. WiCoP includes appropriate procedures to select and establish a security association between WTPs and the AC in the Connection state.

Architecture designs in which authentication is performed at the AC and encryption at the WTPs can be exposed to the threat of replay attacks. Since the AC will not be aware of the exact value of the sequence counter, it will not make the corresponding assignment within the 4-way handshake. This leaves the wireless terminal to accept all incoming frames, including illegitimate frames, as it cannot verify the sequence counter value. Such a threat needs to protected against by allowing the WTP to assign the correct value of the sequence counter. WiCoP accomplishes this by sending the 3rd message of the 4-way handshake within a control message to the WTP, which then updates the sequence counter field before forwarding it to the wireless terminals.

Another issue to consider is that of rogue WTPs using identifiers similar to that of legitimate WTPs. In such instances, a rogue WTP can send a Capabilities message to the AC, thereby causing disconnection of the existing legitimate WTP of the same identifier. It is important for the AC to ignore Capabilities messages received with existing identifiers.

9. Informative References

[RFC4118] Yang, L., Zerfos, P., and E. Sadot, "Architecture Taxonomy for Control and Provisioning of Wireless Access Points (CAPWAP)", RFC 4118, June 2005.

[RFC4564] Govindan, S., Ed., Cheng, H., Yao, ZH., Zhou, WH., and L. Yang, "Objectives for Control and Provisioning of Wireless Access Points (CAPWAP)", RFC 4564, July 2006.

[RFC3990] O'Hara, B., Calhoun, P., and J. Kempf, "Configuration and Provisioning for Wireless Access Points (CAPWAP) Problem Statement", RFC 3990, February 2005.

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