APPLICATION NOTE

AVR2130: Lightweight Mesh Developer Guide

Atmel MCU Wireless

Features

- Atmel® Lightweight Mesh stack specification and APIs
- Lightweight Mesh Software Development Kit (SDK)

Description

This document describes the specification for Lightweight Mesh – the easy to use proprietary low power wireless mesh network protocol from Atmel. This document can be considered a full and complete specification of the protocol and related APIs. This document also describes a reference implementation of the protocol.

The Lightweight Mesh target audience is system designers, embedded programmers, and hardware engineers, evaluating, prototyping, and deploying wireless solutions and products. The Lightweight Mesh stack is delivered as a software development kit, which includes complete source code for the stack components, as well as sample applications.

The audience is assumed to be familiar with the C programming language. Some knowledge of embedded systems is recommended, but not required.

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1. Introduction

1.1 Target Applications

Lightweight Mesh was designed to address the needs of a wide range of wireless connectivity applications. Some of these applications include:

- Remote control
- Alarms and security
- Automatic Meter Reading (AMR)
- Home and commercial building automation
- Toys and educational equipment

1.2 Hardware Requirements

Lightweight Mesh is designed to work with all Atmel IEEE® 802.15.4 transceivers and SoCs. Currently the stack works with AVR®- and ARM®-based MCUs, but given extreme portability and low resource requirements, it can be run on almost any Atmel MCU.

A full list of supported platforms can be found in the Lightweight Mesh Getting Started Guide [4].

1.3 Abbreviations and Terminology

AODV	–	Ad hoc On-Demand Distance Vector
API	–	Application Programming Interface
Device, Node	–	Physical device acting as a part of the network
GPIO	–	General Purpose Input/output
LQI	–	Link Quality Indicator
MAC	–	Medium Access Control
MCU	–	Microcontroller Unit
MIC	–	Message Integrity Code
NWK	–	Network layer
PAN	–	Personal Area Network
PHY	–	Physical layer
RAM	–	Random Access Memory
RSSI	–	Received Signal Strength Indicator
SDK	–	Software Development Kit
SoC	–	System-on-Chip
User, Customer	–	Entity using Lightweight Mesh in a final product

2. Lightweight Mesh Protocol Overview

2.1 Features

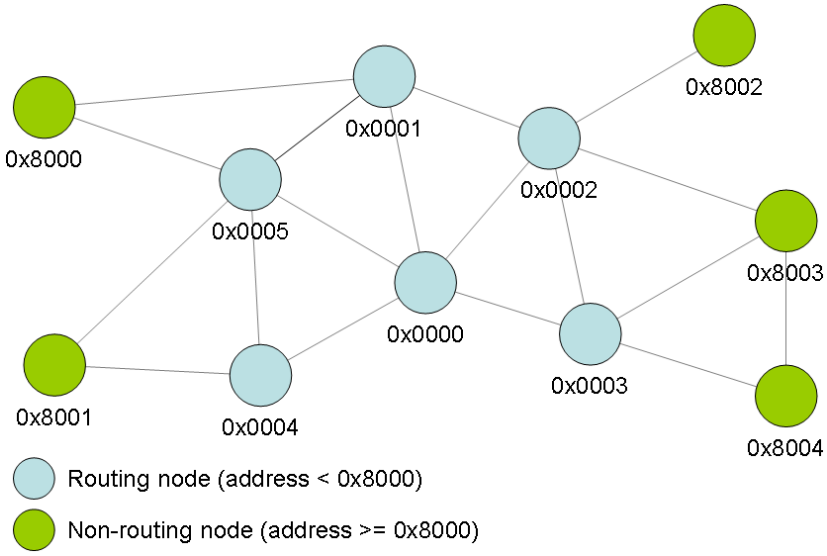
The current implementation of the Lightweight Mesh protocol has the following features:

- Simplicity of configuration and use
- Up to 65535 nodes in one network (theoretical limit)
- Up to 65535 separate PANs on one channel
- 15 independent application endpoints
- No dedicated node is required to start a network
- No periodic service traffic occupying bandwidth
- Two distinct types of nodes:
  - Routing (network address < 0x8000)
  - Non-routing (network address ≥ 0x8000)
- Once powered on node is ready to send and receive data; no special joining procedure is required
- No child-parent relationship between the nodes
- Non-routing nodes can send and receive data to/from any other node (including non-routing nodes), but they will never be used for routing purposes
- Route discovery happens automatically if route to the destination is not known
- Routing table is updated automatically based on the data from the received and transmitted frames
- Optional support for AODV routing
- Optional support for multicast communication
- Duplicate frames (broadcast or multipath unicast) are rejected
- Small footprint (8KB of Flash and 4KB of RAM for a typical application)

2.2 Network Topology

Network topology and possible device types are illustrated by Figure 2-1. Nodes shown in blue are routing nodes; they form a core of the typical network and expected to be mains-powered. Nodes shown in green are non-routing nodes; they are part of the network and they can send and receive data as long as they are in range and have the radio turned on, but they are not expected to be available all the time (they can be sleeping nodes, mobile nodes going out of range, etc). Non-routing nodes will not be used for routing purposes, so they cannot act as range extenders, and typically will be located at the edge of the network.

Figure 2-1. Network Topology and Device Types



2.3 Provided Services

Lightweight Mesh provides the following core services:

- Basic data services (send and receive data)
- Acknowledgments
- Routing
- Basic security
- Power management of the radio transceiver
- Interface to the advanced features of the radio transceiver (encryption, energy detection, random number generation, etc)

An application running Lightweight Mesh is responsible for:

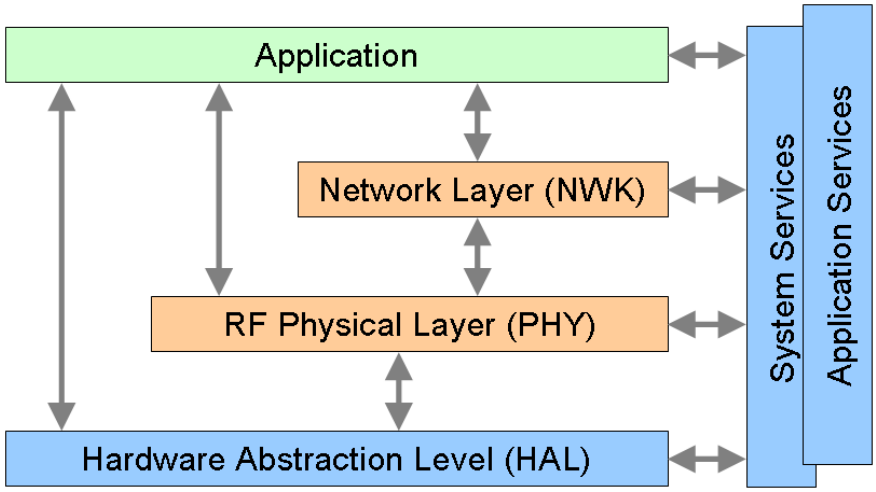
- Network management (discovery, joining, commissioning, etc)
- Advanced network operation scenarios (sleeping routers, parent-child relationship, data delivery to the sleeping nodes, etc)
- Retries to send data in case of failures
- Defining message payload format
- Advanced security
- Power management of the MCU
- Interfacing hardware peripherals (ADC, PWM, EEPROM, etc)

3. Lightweight Mesh Architecture

3.1 Architecture Highlights

High level architecture of the Lightweight Mesh stack is presented on the Figure 3-1. Lightweight Mesh code is separated into a number of logical levels each providing a set of APIs accessible for the user. The Stack is designed to provide only functions absolutely necessary for wireless communication, and it is expected that the rest will be created by the user, or provided by third-party libraries, if required.

Figure 3-1. Lightweight Mesh Architecture



- Hardware Abstraction Layer (HAL) provides basic hardware dependent functionality, like hardware timer, sleep control, GPIO access for the radio interface
- Radio physical layer (PHY) provides functions for radio transceiver access. Some of them are accessible only by the network layer (request to send data, data indication); some of them can be used from the application (channel selection, random number generation, energy detection, etc.)
- Network layer (NWK) provides core stack functionality, which is described in detail throughout this document
- System services provide common functions for all layers, which are necessary for normal stack operation. System services include basic types and definitions, software timers, default configuration parameters, encryption module access, etc.
- Application services include modules that are not required by the stack, but are common for most applications. Currently the only service of this type is Over-The-Air upgrade (OTA). Application services are out of the scope of this document

3.2 Naming Conventions

Lightweight Mesh uses a well defined set of naming conventions that make it very easy to read the source code and reduce application development time. Here are the basic rules:

- Each API function name is prefixed by the name of the layer where the function resides. For example, the *NWK_SetAddr()* function is contributed by the network layer of the stack
- Each function name prefix is followed by an underscore character separating the prefix from the descriptive function name
- The descriptive function name may have a *Req*, *Ind* or *Conf* suffix, indicating the following:

- *Req* corresponds to the requests from the user application to the stack (for example, *NWK_DataReq()*)
- *Ind* corresponds to the asynchronous indication of events propagated to the user application from the stack (for example, *NWK_DataInd()*)
- *Conf* corresponds to the user-defined callbacks for the asynchronous requests, which confirm the request's execution

- Each structure and type name carries a *_t* suffix, standing for type
- Enumeration and macro variable names are in capital letters

It is recommended that the application developer adhere to the aforementioned naming conventions in the user application.

3.3 File System Layout

The file system layout of the SDK closely reflects the architecture of the Lightweight Mesh stack.

Table 3-1. Lightweight Mesh SDK File System Layout

Directory	Table Text
apps	Sample applications
doc	Documentation
hal	Hardware abstraction layer
nwk	Network layer
phy	Radio physical layer
service	Application services
sys	System services
tools	Supporting tools and PC applications

4. Network Layer Specification

4.1 General Lightweight Mesh Frame Format

The Lightweight Mesh network header and application payload are encapsulated inside the standard IEEE 805.15.4 data frame payload (see [1]), but the stack itself does not adhere to the standard, so it will not receive and process IEEE 805.15.4 command frames. Figure 4-1 illustrates a general frame format composed of an IEEE 805.15.4 MAC header, network header, application payload, optional message integrity code (MIC) and a check sum (CRC).

Figure 4-1. General Lightweight Mesh Frame Format

16	8	16	16	16	8	8	16	16	4	4	0/16	Variable	0/32	16
Frame Control	Sequence number	PAN ID	Destination Address	Source Address	Frame Control	Sequence number	Source Address	Destination Address	Source Endpoint	Destination Endpoint	Multicast Header	Variable	MIC	CRC
MAC Header					Network Header							Payload	MIC	CRC

The following settings are used for a MAC Frame Control Field as described in [1]:

- Frame Type: Data
- Security Enabled: False
- Frame Pending: False
- Acknowledgment Request: True for unicast frames and False for broadcast frames
- PAN ID Compression: True
- Destination Addressing Mode: 16-bit short address
- Frame Version: 0
- Source Addressing Mode: 16-bit short address

This gives two possible values for the MAC Frame Control Field that can be generated and recognized by the stack: 0x8841 for broadcast frames, and 0x8861 for unicast frames.

4.1.1 Frame Control Field

The Frame Control field is 1 byte in length and contains control information for the frame. The Frame Control field shall be formatted as illustrated in the Figure 4-2.

Figure 4-2. Lightweight Mesh Frame Control Field Format

Bits: 0	1	2	3	4-7
Ack Request	Security Enabled	Link Local	Multicast	Reserved
Network Frame Control				

4.1.1.1 Acknowledgment Request Subfield

The Acknowledgment Request subfield is 1 bit in length and specifies whether an acknowledgment is required from the destination node. If this subfield is set to one, the destination node shall send an acknowledgment command if frame was received and processed. If this subfield is set to zero, the destination device shall not send an acknowledgment frame (for exceptions see Section 4.3).

4.1.1.2 Security Enabled Subfield

The Security Enabled subfield is 1 bit in length, and it shall be set to one if the frame payload is encrypted, and shall be set to zero otherwise. Message Integrity Code (MIC) should be present if the Security Enabled subfield is set to one.

4.1.1.3 Link Local Subfield

The Link Local subfield is 1 bit in length, and it may be set to one to prevent neighboring nodes from rebroadcasting a frame. This subfield is only valid for broadcast frames and has no effect on unicast frames.

4.1.1.4 Multicast Subfield

The Multicast subfield is 1 bit in length, and it shall be set to one if the destination address is a group address, and shall be set to zero otherwise. Multicast Header should be present if the Multicast subfield is set to one.

4.1.1.5 Reserved Subfield

The Reserved subfield is 4 bits in length, and it shall be set to 0.

4.1.2 Sequence Number Field

The Sequence Number field is 1 byte in length and specifies the sequence identifier for the frame. The Sequence Number field shall be increased by 1 for every outgoing frame originating on the node and it should not change for routed frames.

4.1.3 Source Address Field

The Source Address field is 2 bytes in length and specifies the network address of the node originating the frame.

4.1.4 Destination Address Field

The Destination Address field is 2 bytes in length and specifies the network address of the destination node or group address for multicast messages. Meaning of the Destination Address field is defined by the Multicast subfield of the Network Frame Control field. The Destination Address field can be set to 0xffff for broadcast frames.

4.1.5 Source Endpoint Field

The Source Endpoint field is 4 bits in length and specifies the source endpoint identifier. Value of 0 is reserved for a stack command endpoint.

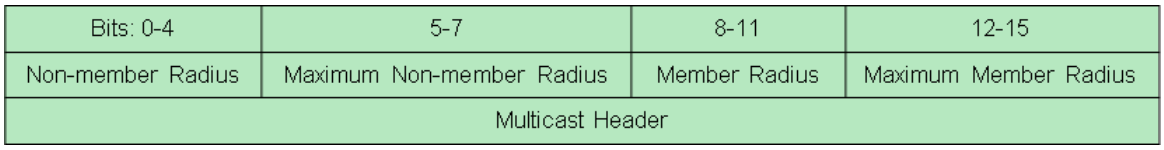
4.1.6 Destination Endpoint Field

The Destination Endpoint field is 4 bits in length and specifies the destination endpoint identifier. Value of 0 is reserved for a stack command endpoint.

4.1.7 Multicast Header Field

The Multicast Header field is 2 bytes in length and contains control information for the multicast frame. The Multicast Header field shall be formatted as illustrated in the Figure 4-3.

Figure 4-3. Lightweight Mesh Multicast Header Format



4.1.7.1 Non-member Radius Subfield

The Non-member Radius subfield is 4 bits in length and specifies remaining radius (number of hops) to which nodes that do not belong to the group indicated by the Destination Address field will distribute a frame. If a node that does not belong to the group receives a frame with Non-member Radius subfield equal to 0 it should indicate this frame to the application, but should not resend it any further. On the originating node this subfield should have the same value as Maximum Non-member Radius subfield. Nodes that belong to the group indicated by the Destination Address field shall set Non-member Radius subfield equal to the value of Maximum Non-member Radius subfield before resending a frame.

4.1.7.2 Maximum Non-member Radius Subfield

The Maximum Non-member Radius subfield is 4 bits in length and specifies maximum radius (number of hops) to which nodes that don't belong to the group indicated by the Destination Address field will distribute a frame. The value of this subfield is set by the originating node and should not be changed by the resending nodes.

4.1.7.3 Member Radius Subfield

The Member Radius subfield is 4 bits in length and specifies remaining radius (number of hops) to which nodes that belong to the group indicated by the Destination Address field will distribute a frame. If a node that belongs to the group receives a frame with Member Radius subfield equal to 0 it should indicate this frame to the application, but should not resend it any further. On the originating node this subfield should have the same value as Maximum Member Radius subfield. Nodes that do not belong to the group indicated by the Destination Address field shall set Member Radius subfield equal to the value of Maximum Member Radius subfield before resending a frame.

4.1.7.4 Maximum Member Radius Subfield

The Maximum Member Radius subfield is 4 bits in length and specifies maximum radius (number of hops) to which nodes that don't belong to the group indicated by the Destination Address field will distribute a frame. The value of this subfield is set by the originating node and should not be changed by the resending nodes.

4.2 Format of Individual Command Frames

4.2.1 Acknowledgment Command Frame Format

Acknowledgment Command frame is generated in response to the received frame if Ack Request subfield of the Network Frame Control field is set to one. Additionally Acknowledgment Command frame is generated during native route discovery process to establish reverse route (see Section 4.3 for details). Figure 4-4 illustrates the Acknowledgment Command frame format.

Figure 4-4. Acknowledgment Command Frame Format

Bits: 8	8	8
Command ID (0x00)	Sequence Number	Control Message

4.2.1.1 Command ID Field

The Command ID field is 1 byte in length, and it contains a constant value (0x00).

4.2.1.2 Sequence Number Field

The Sequence Number field is 1 byte in length, and it contains a network sequence number of a frame that is being acknowledged.

4.2.1.3 Control Message Field

The Control Message field is 1 byte in length, and it contains an arbitrary value that can be set on the sending side. This filed can be used to provide additional instruction to the receiving side.

4.2.2 Route Error Command Frame Format

Route Error Command frame is generated in response to the received frame in case if routing was required and node could not locate a valid routing table entry to perform the routing. Figure 4-5 illustrates Route Error Command frame format.

Figure 4-5. Route Error Command Frame Format

Bits: 8	16	16	8
Command ID (0x01)	Source Address	Destination Address	Multicast

4.2.2.1 Command ID Field

The Command ID field is 1 byte in length, and it contains a constant value (0x01).

4.2.2.2 Source Address Field

The Source Address field is 2 bytes in length, and it contains a source network address from the frame that cannot be routed.

4.2.2.3 Destination Address Field

The Destination Address field is 2 bytes in length, and it contains a destination network address or a group ID (as indicated by Multicast field) from the frame that cannot be routed.

4.2.2.4 Multicast Field

The Multicast field is 1 byte in length, and it shall be set to 0 if Destination Address field contains a network address or to 1 if Destination Address field contains a group ID.

4.2.3 Route Request Command Frame Format

Route Request Command frame is generated in response to the application request to send the data in case if the Routing Table does not contain a valid entry for the destination address. Figure 4-6 illustrates Route Request Command frame format.

Figure 4-6. Route Request Command Frame Format

Bits: 8	16	16	8	8
Command ID (0x02)	Source Address	Destination Address	Multicast	Link Quality

4.2.3.1 Command ID Field

The Command ID field is 1 byte in length, and it contains a constant value (0x02).

4.2.3.2 Source Address Field

The Source Address field is 2 bytes in length, and it contains a source network address from the frame that cannot be routed.

4.2.3.3 Destination Address Field

The Destination Address field is 2 bytes in length, and it contains a network address of the destination node or a group ID of the destination group as indicated by Multicast field.

4.2.3.4 Multicast Field

The Multicast field is 1 byte in length, and it shall be set to 0 if Destination Address field contains a network address or to 1 if Destination Address field contains a group ID.

4.2.3.5 Link Quality Field

The Link Quality field is 1 byte in length, and it contains a link quality value of the potential route accumulated over all hops towards the destination. Originating node should set Link Quality field to 255. Each node resending a Route Request Command frame must update the Link Quality field value with the value of LQI from the received frame.

4.2.4 Route Reply Command Frame Format

Route Reply Command frame is generated in response to the received Route Request Command frame in case if newly discovered route is better than any of the previously discovered routes (see Section 4.3 for details). Figure 4-7 illustrates Route Reply Command frame format.

Figure 4-7. Route Reply Command Frame Format

Bits: 8	16	16	8	8	8
Command ID (0x03)	Source Address	Destination Address	Multicast	Forward Link Quality	Reverse Link Quality

4.2.4.1 Command ID Field

The Command ID field is 1 byte in length, and it contains a constant value (0x03).

4.2.4.2 Source Address Field

The Source Address field is 2 bytes in length, and it contains a source network address from the frame that cannot be routed.

4.2.4.3 Destination Address Field

The Destination Address field is 2 bytes in length, and it contains a network address of the destination node or a group ID of the destination group as indicated by Multicast field.

4.2.4.4 Multicast Field

The Multicast field is 1 byte in length, and it shall be set to 0 if Destination Address field contains a network address or to 1 if Destination Address field contains a group ID.

4.2.4.5 Forward Link Quality Field

The Forward Link Quality field is 1 byte in length, and it contains a value of the Link Quality field from the corresponding Route Request Command Frame. The value of this field should not be changed by nodes resending the response towards the originator.

4.2.4.6 Reverse Link Quality Field

The Reverse Link Quality field is 1 byte in length, and it contains a link quality value of the discovered route accumulated over all hops towards the originator. Originating node should set Reverse Link Quality field to 255. Each node resending a Route Reply Command frame must update Link Quality field value with the value of LQI from the received frame. The value of Reverse Link Quality is used to compare routes during the route discovery process.

4.3 Routing

4.3.1 Overview

Lightweight Mesh supports two routing algorithms:

- Native routing.
  This is the original Lightweight Mesh algorithm; it is simple, compact and does not use additional commands to perform route discovery. But this algorithm cannot guarantee that discovered routes are optimal since it performs only local optimizations. It also cannot be used to discover routes to the groups.
- AODV routing.
  This is more standard algorithm; it uses additional commands to perform route discovery and route discovery process might lake longer time. This algorithm selects optimal routes and can be used to discover routes to the groups.

Both routing algorithms use Routing Table for their operation. A Routing Table consists of routing entries. Each routing entry includes the fields described in Table 4-1. The Routing Table entries have the same format for both algorithms, but they use slightly different approach to entry maintenance.

Table 4-1. Routing Table Entry Fields

Name	Size, bits	Description
fixed	1	Indicates a fixed entry that cannot be removed even if destination node is no longer reachable. Stack will never create entries with this field set to one, but application may use it for creating static routes
multicast	1	Indicates a multicast entry. If this field is set to one then *dstAddr* field contains a group ID
reserved	2	Reserved and should be set to 0
score	4	Indicates entry health. If the value of this field reaches 0, entry is removed from the Routing Table
dstAddr	16	Destination network address or a group ID as indicated by *multicast* field
nextHopAddr	16	Network address of the next node on the route towards the destination node
rank	8	Indicates how often entry is used. Entry with the lowest rank is replaced first if Routing Table is full and a new entry has to be added
lqi	8	Link quality of the route: • For native routing algorithm this field contains LQI of the last received from the node with address *nextHopAddr*. Value of this field might be updated by the stack in run time • For AODV routing algorithm this field contains a value of the Reverse Link Quality field from the Route Reply Command that was used to establish this route. Stack will not update value of this field after the route has been discovered

Routing Table entries are accessible to the application though a set of APIs are described in Chapter 5. No verification is performed against application modifications to the Routing Table, so application needs to be extra careful when making changes to the Routing Table. Application has to make sure that at any time there is at least one entry in the Routing Table that is not fixed and available for allocation.

For the purpose of route discovery Destination Address is an actual network address of the node if multicast support is disabled, and a combination of a Destination Address field and Multicast flag if multicast support is enabled.

4.3.2 Native Routing

4.3.2.1 Route Discovery and Establishment

In Lightweight Mesh with the native routing algorithm there is no special route discovery procedure; routes are discovered as part of normal data delivery. This way, the penalty of not having a route is very low and comparable to the cost of sending a regular broadcast frame.

Route discovery algorithm is illustrated below. Nodes marked “1”, “2”, and “3” are routing nodes. This example makes the following assumptions:

- Node 1 wants to send data to node 3
- Routing Tables on all nodes are empty
- There is no direct path between node 1 and node 3

Initial network configuration is shown on the Figure 4-8.

Figure 4-8. Initial Network Configuration

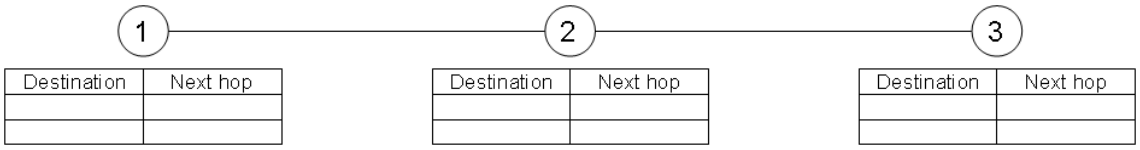
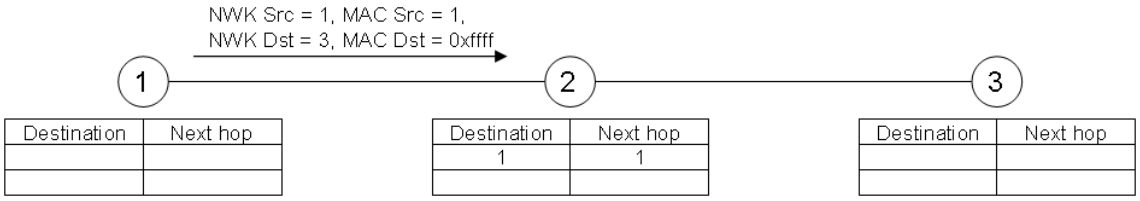
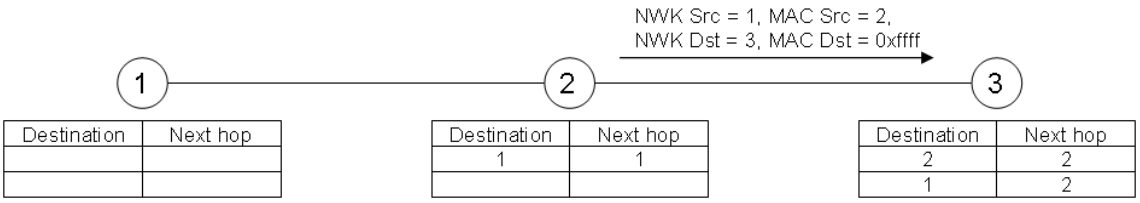


Figure 4-9. First Step of a Data Transfer Involving Route Discovery



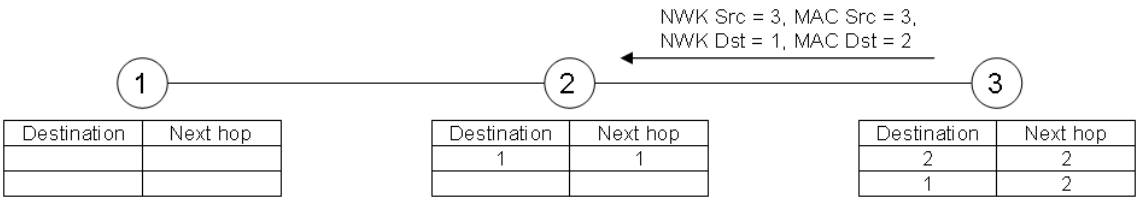
1. Node 1 sends a frame with the Network Destination Address set to 3, and the MAC Destination Address set to 0xffff.
2. Node 2 receives this frame, and adds the entry for node 1 to its Routing Table.

Figure 4-10. Second Step of a Data Transfer Involving Route Discovery



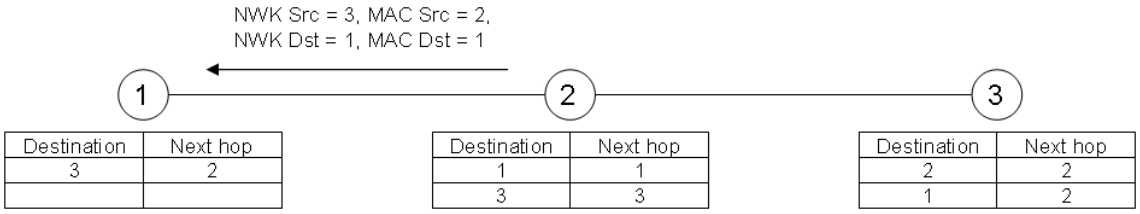
3. Node 2 broadcasts the frame (because MAC Destination Address is set to 0xffff).
4. Node 3 receives this frame, and adds the entry for node 2 to its Routing Table.
5. Node 3 adds an entry for node 1 to its Routing Table (from a Network Source Address).

Figure 4-11. Third Step of a Data Transfer Involving Route Discovery



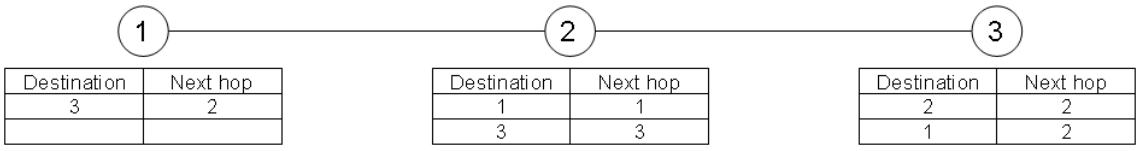
6. Node 3 handles the frame and sends an Acknowledgment frame, even if one was not requested. This is done to establish a reverse route. Node 3 now knows the route to node 1, so a unicast frame is sent.

Figure 4-12. Final Step of a Data Transfer Involving Route Discovery



7. Node 2 receives the frame and adds the route to node 3 to its Routing Table.
8. Node 2 has a route entry for node 1, so it routes the received frame to its final destination.
9. Node 1 receives the frame and adds the route to node 3 to its Routing Table.

Figure 4-13. Final Network Configuration after a Data Transfer Involving Route Discovery



Now a route between node 1 and node 3 is established and it will be used for the following frames. Note that during route discovery, all nodes along the route learned how to route data to the destination node. Those route entries will be used for routing purposes without further route discovery. Eventually, given big enough Routing Tables, all nodes in the network will discover all possible (used) routes.

Also note that for some nodes discovery of one route created more than one entry in the Routing Table. This is a common property of the routing algorithms and it should be kept in mind when selecting Route Table size for nodes that are expected to route a lot of traffic. At the same time there is an upper bound on the number of entries in the routing table which is the maximum number of nodes in the network.

4.3.2.2 Route Maintenance and Utilization

The Routing Table is updated with every sent or received frame.

When a frame is received, the Routing Table is updated in the following way:

1. No action is performed if the source MAC address indicates that the sending device is a non-routing node (it cannot be used as part of the route).
2. If there is an entry for the source network address, and this entry contains a next hop address different from the source MAC address of the received frame, and the LQI of the received frame is better than the LQI in the routing entry, then the entry is updated to use the source node as the next hop. Entry score is set to NWK_ROUTE_DEFAULT_SCORE.

3. If there is an entry for the source network address, and this entry contains a next hop address different from the source MAC address of the received frame, and if the received frame is a route discovery frame (MAC address is 0xffff and network address is not 0xffff), then the entry is updated to use the source node as the next hop. Entry score is set to NWK_ROUTE_DEFAULT_SCORE.
4. If there is no entry for the source network address, then a new entry is created in the Routing Table.
5. LQI of the entry (existing or newly created) is set to the LQI of the received frame.

When a frame is sent the routing table is updated in the following way:

6. If there is an entry for the Destination Address, then
    1. If the frame was sent successfully, then the entry score is set to NWK_ROUTE_DEFAULT_SCORE.
    2. Otherwise the entry score is decreased. If the entry score drops to 0, then the entry is removed from the Routing Table.
7. If there is no entry for the Destination Address, then no action is performed.

Essentially this algorithm performs local optimizations, so it establishes and maintains routes with the best link quality on each link, but it does not guarantee shortest routes.

4.3.2.3 Route Invalidation and Removal

Routing Table entries never expire or timeout, but there are a few ways an entry can be altered:

1. Routing Table entry is replaced by a new entry if there are no free entries, and a new entry has to be placed in the Routing Table. The least active entries are replaced first (activity of the entry is indicated by the *rank* field in the entry).
2. Routing Table entry is removed if its score drops to 0.
3. Routing Table entry is removed when a Route Error command, with the Destination Address field equal to the route entry destination address, is received.

4.3.3 AODV Routing

4.3.3.1 Route Discovery and Establishment

AODV routing algorithm implies a special route discovery procedure. This procedure is stateful, which means that every node participating in the route discovery must keep track of the progress and update its information about the routes being discovered based on the newly received frames. Information about candidate routes is stored in the Route Discovery Table. After route discovery process is complete this information is transferred into the Routing Table. Size of the Route Discovery Table defines how many route discovery processes the node can participate in simultaneously. Fields of the Route Discovery Table are described in Table 4-2. A Route Discovery Table entry corresponding to the route discovery process is uniquely identified by the triplet of fields *(srcAddr*, *dstAddr*, *multicast)*.

Table 4-2. Route Discovery Table Entry Fields

Name	Size, bits	Description
srcAddr	16	Network address of the node requesting the route
dstAddr	16	Network address of the destination node or a group ID as indicated by *multicast* field
multicast	8	Indicates a multicast route discovery. If this field is set to 1 then *dstAddr* field contains a group ID
senderAddr	16	Network address of the node from which the last selected Route Request Command frame was received. This is a next hop address towards the source node and all Route Reply Command frames will be sent to this address
forwardLinkQuality	8	Accumulated Link Quality from a source node
reverseLinkQuality	8	Accumulated Link Quality from a destination node
timeout	16	Amount of time left for the route discovery process

Route discovery process is initiated if there is no entry in the Routing Table corresponding to the Destination Address of the current data transmission request.

Initiating node should check if an entry matching current request parameters already exists in the Route Discovery Table. If such entry exists then node should wait for completion of ongoing route discovery process and use its results at the end.

Then node should create a new entry in the Route Discovery Table with parameters from the current data transmission request. If the Route Discovery Table is full and a new entry cannot be added, then data transmission request should be confirmed with NWK_NO_ROUTE_STATUS status.

A route discovery process continues with the source node generating a Route Request Command frame. This frame is sent as a local broadcast, which means that only nodes within direct reach from the source node will receive it. Link Quality field of the Route Request Command frame must be set to 255.

Any routing node receiving a Route Request Command frame must calculate updated link quality value based on the Link Quality field of the Route Request Command frame and LQI of the received frame. The Node must then check in its Route Discovery Table if an entry for this route discovery process already exists:

1. If an entry does not exist a new entry should be created:
    1. If Route Discovery Table is full and it is impossible to add a new entry, any further processing of the Route Request Command frame should be terminated.
    2. If new entry was added to the Route Discovery Table the value of *forwardLinkQuality* field should be set to the updated link quality value. Then the node should generate Route Request Command frame with Link Quality field set to the value of *forwardLinkQuality* field of the Route Discovery Table entry.
2. Otherwise node should check the value of *forwardLinkQuality* field:
    1. If updated link quality value is larger than the value of *forwardLinkQuality* field the node should update information in the Route Discovery Table entry based on the information from the received Route Request Command frame. The node should then generate Route Request Command frame with Link Quality field set to the value of *forwardLinkQuality* field of the Route Discovery Table entry.
    2. Otherwise node should terminate any further processing of the Route Request Command frame.
3. If the node is the destination node as indicated by the Route Request Command frame then, instead of generating Route Request Command frame, the node must generate Route Reply Command frame setting Forward Link Quality field equal to the value of *forwardLinkQuality* field of the Route Discovery Table entry and Reverse Link Quality field equal to 255.

Any routing node receiving a Route Reply Command frame must calculate updated reverse link quality value based on the Reverse Link Quality field of the Route Reply Command frame and LQI of the received frame. The node must then check in its Route Discovery Table if an entry for this route discovery process exists:

1. If an entry does not exist, any further processing of the frame should be terminated.
2. Otherwise the node should check the value of *reverseLinkQuality* field:
    1. If the value of *reverseLinkQuality* field is less than the value of Forward Link Quality field of the Route Reply Command frame, the node should update *reverseLinkQuality* field with the value of Forward Link Quality field and update routing tables according to the information from the Route Discovery Table and Route Reply Command frame. The node should then generate Route Reply Command frame with Link Quality field set to the value of updated reverse link quality value.
    2. Otherwise the node should terminate any further processing of the Route Request Command frame.

4.3.3.2 Route Maintenance and Utilization

The Routing Table is updated only based on the results for transmitted frames. When a frame is sent the Routing Table is updated in the following way:

1. If there is an entry for the Destination Address, then:
    - If the frame was sent successfully, the entry score is set to NWK_ROUTE_DEFAULT_SCORE.

- Otherwise the entry score is decreased. If the entry score drops to 0, the entry is removed from the Routing Table.

2. If there is no entry for the Destination Address, no action is performed.

This means that routes discovered during the route discovery process are never updated based on the received frames and the only way for the route to change is to be removed from the Routing Table and be discovered again. This algorithm makes sure that during normal operation routes will follow the same optimization criteria which was used for route discovery.

4.3.3.3 Route Invalidation and Removal

Routing Table entries never expire or timeout, but there are a few ways an entry can be altered:

1. Routing Table entry is replaced by a new entry if there are no free entries, and a new entry has to be placed in the Routing Table. The least active entries are replaced first (activity of the entry is indicated by the *rank* field in the entry).
2. Routing Table entry is removed if its score drops to 0.
3. Routing Table entry is removed when a Route Error command, with the Destination Address field equal to the route entry destination address, is received.

4.4 Transmission, Reception, and Acknowledgement

Any received frame undergoes duplicate rejection screening to detect and reject possible duplicate frames. This screening is performed using Duplicate Rejection Table – a table that for each node contains a network sequence number of the last received frame. The same Duplicate Rejection Table is used to keep track of already resent broadcast frames and for detection and prevention of the loops in the routes. The sections below assume that received frame has passed through the duplicate rejection filter.

4.4.1 Unicast Messaging

Unicast frames are frames with a Multicast subfield of the Network Frame Control field set to 0 and destination network address not equal to 0xffff.

When unicast message has to be sent:

1. If there is an entry in the Routing Table for the Destination Address of the frame, then destination MAC address of the frame is set to the *nextHopAddr* field of the corresponding Routing Table entry.
2. If there is no entry in the Routing Table for the destination network address of the frame, then route discovery process is initiated.

A received frame has to be routed if the MAC destination address is equal to the node's own address and the network destination address is not equal to the node's own address.

When routing is needed, the following conditions are evaluated:

1. If there is an entry in the Routing Table for the destination network address, then the destination MAC address of the frame is replaced by the next hop address from the Routing Table, and the frame is sent.
2. If there is no entry in the Routing Table for the destination network address, then a Route Error command is sent to the originator of the frame.

A received frame is acknowledged in two cases:

3. If acknowledgment was explicitly requested by the application. In this case acknowledgment is sent after application was notified about the frame. This gives a chance to interrupt the acknowledgment process.
4. If native route discovery is used and received frame had a unicast network address and broadcast MAC address (route discovery). In this case acknowledgment is used to facilitate discovery of the reverse route.

4.4.2 Broadcast Messaging

Broadcast frames are frames with a Multicast subfield of the Network Frame Control field set to 0 and destination network address equal to 0xffff.

When broadcast frame has to be sent, destination MAC address is set to 0xffff (broadcast) and frame is transmitted. Route discovery is not performed for broadcast frames.

When broadcast frame is received the node has to resend the frame without making any additional modifications to the network header.

Broadcast fames cannot be acknowledged.

4.4.3 Multicast Messaging

Multicast frames are frames with a Multicast subfield of the Network Frame Control field set to 1 and Destination Address field set to the group address. In addition to a regular Network Header, multicast frames should have a Multicast Header.

For the purpose of multicast message delivery all nodes in the network are divided into two sets:

- Member nodes – nodes that belong to the group indicated by the Destination Address field
- Non-member nodes – all other nodes in the network

When multicast message has to be sent:

1. Multicast Header subfields should be filled as following: Maximum Non-member Radius and Maximum Member Radius subfields should be set as per application request, Non-member Radius, and Member Radius subfields should be set equal to the Maximum Non-member Radius and Maximum Member Radius subfields respectively.
2. If originating node is a member of the group then frame is sent as a broadcast. This mode can be used with either native or AODV route discovery enabled since actual route discovery will not be performed.
3. If originating node is not a member of the group the frame is sent as a regular unicast frame towards the closest member node. This mode requires AODV route discovery process to be used since native route discovery cannot discover multicast routes.

When multicast frame is received by the member node:

1. If frame is received as a unicast the node should resend the frame as a broadcast without making any modifications to the Multicast Header.
2. If frame is received as a broadcast then:
    1. If Member Radius subfield is above 0 the node should decrement Member Radius subfield by one, set the value of Non-member Radius subfield equal to the value of Maximum Non-member Radius subfield and send the frame as a broadcast.
    2. If Member Radius subfield is 0 the message should be indicated to the application and any further processing of the frame should be terminated.

When multicast frame is received by the non-member node:

1. If frame is received as a unicast then it should be forwarded towards the next hop node on the route to the group identified by the Destination Address.
2. If frame is received as a broadcast then:
    1. If Non-member Radius subfield is above 0 then node should decrement Non-member Radius subfield by one, set the value of Member Radius subfield equal to the value of Maximum Member Radius subfield and send the frame as a broadcast.
    2. If Non-Member Radius subfield is 0 then any further processing of the frame should be terminated.

Multicast messages cannot be acknowledged.

4.4.4 Link Local Messaging

A broadcast frame sent with Link Local subfield of the Network Frame Control field set to 1 will not be resent by the receiving nodes. In all other respects link local broadcast frames are processed as regular broadcast frames.

A unicast frame sent with Link Local subfield of the Network Frame Control field set to 1 will not be routed, but will be received if destination device is within a local link range.

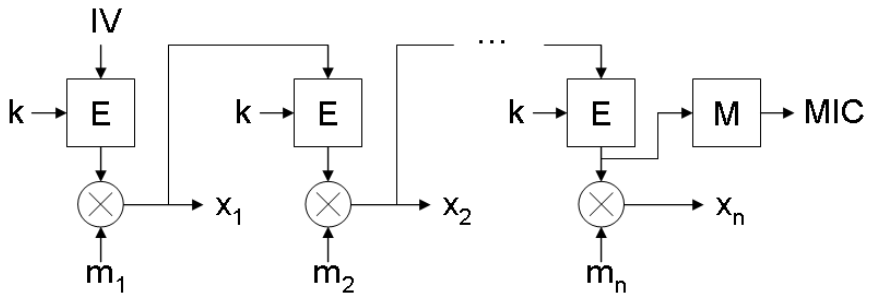
4.4.5 Broadcast PAN ID Messaging

A frame sent to the broadcast PAN ID (0xffff) is received by nodes with the requested destination address in all immediately accessible PANs. Frames with broadcast PAN ID cannot be routed or acknowledged.

4.5 Security

Lightweight Mesh support two base encryption algorithms: hardware accelerated AES-128 (where supported by the hardware) and software XTEA (all platforms). Both AES and XTEA are block-based algorithms, so messages that exceed the size of the block have to be split into a set of blocks. After splitting and encryption, blocks are chained in order to derive a Message Integrity Code (MIC) that covers the entire message. The chaining method is illustrated in the Figure 4-14. Only the encryption operation is utilized for both encryption and decryption of messages; symmetry of the binary exclusive-or operation is used to achieve this.

Figure 4-14. Encryption Blocks Chaining

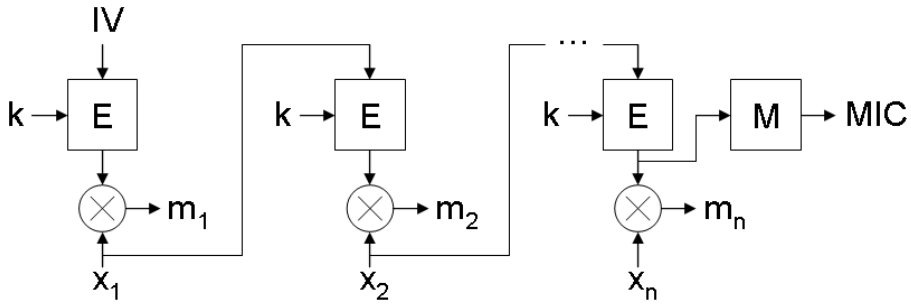


Here:

- *IV* – initialization vector, which is constructed based on the information from the frame header
- *K* – 128-bit key
- *E* – base encryption block (AES or XTEA)
- *M* – message integrity code transform
- *MIC* – message integrity code (32 bits)
- $m_1, m_2, \ldots, m_n$ – 128-bit blocks of the unencrypted message
- $x_1, x_2, \ldots, x_n$ – 128-bit blocks of the encrypted message

Decryption is performed in a similar way. It is illustrated in Figure 4-15.

Figure 4-15. Decryption Blocks Chaining



Message integrity code is included in all encrypted frames. It allows verification of the message integrity, validation of the key, and also protection against altering the network header of the message.

Few notes about security:

- There is no protection against replay attacks; it should be implemented on the application layer if required
- The entire network uses the same shared encryption key, so if additional protection is required, it should be implemented on the application layer as well
- Although theoretically AES is stronger than XTEA, for external radio chips, encryption keys are sent in plain text over the SPI bus, so if there is the possibility of physical access to the devices, software XTEA implementation might offer stronger overall protection

5. Application Programming

5.1 Typical Application Structure

Typical standalone Lightweight Mesh application has a structure as shown below.

Typical standalone Lightweight Mesh application

```
static void APP_TaskHandler(void)
{
  // Put your application code here
}

int main(void)
{
  SYS_Init();

  while (1)
  {
    SYS_TaskHandler();
    APP_TaskHandler();
  }
}
```

On the other hand, if Lightweight Mesh is used inside another environment or task scheduler, it is not necessary to follow this structure. The only requirement is that *SYS_Init()* is called before any other Lightweight Mesh function and *SYS_TaskHandler()* is called as often as possible. For a description of good, event-driven, application design practices, see [3].

5.2 Basic Network Configuration

Below is a list of parameters that should be set in order to send and receive data.

5.2.1 Network Address

The network address of the node is set via *NWK_SetAddr()* function. Parameter *addr* cannot take value of 0xffff as it is reserved for broadcast frames.

Setting the network address

```
NWK_SetAddr(0x0001);
```

5.2.2 Network Identifier

The network identifier (PAN ID) of the node is set via the *NWK_SetPanId()* function. Parameter *panId* cannot take value of 0xffff as it is reserved.

Setting the network identifier

```
NWK_SetPanId(0x1234);
```

5.2.3 Frequency Channel

The frequency channel of the node is set via *PHY_SetChannel()* function. Valid range of values for the *channel* parameter on 2.4GHz radios is 11 – 26 (0x0b – 0x1a). For sub-GHz radios this parameter represents channel number with a valid range of 0 – 10 (0x00 – 0x0a) if frequency band is set to 0, or frequency index otherwise. Refer to the description of the *CC_BAND* and *CC_NUMBER* settings in [4].

Setting the frequency channel

```
PHY_SetChannel(0x0f);
```

5.2.4 Frequency Band

The frequency band of the node is set via the *PHY_SetBand()* function. This function is only available for sub-GHz radios.

Frequency bands and corresponding frequencies are described in [4].

Setting the frequency band

```
PHY_SetBand(2);
```

5.2.5 Modulation Mode

The modulation mode of the node is set via the *PHY_SetModulation()* function. This function is only available for sub-GHz radios. See the description of *TRX_CTRL_2* register in [4] for details on various modulation modes.

Setting the modulation mode

```
PHY_SetModulation(0x35);
```

5.2.6 Transmit Power

The transmit power the node is set via the *PHY_SetTxPower()* function. This function takes radio-dependent value as a parameter. Refer to the datasheet for a specific PHY for complete description of the valid input values.

Setting the transmit power

```
PHY_SetTxPower(0x00);
```

5.2.7 Receiver State

The transceiver state of the node is set via the *PHY_SetRxState()* function.

Setting the transceiver state

```
PHY_SetRxState(true);
```

5.2.8 Security Key

The security key of the node is set via the *NWK_SetSecurityKey()* function. The size of the security key is 16 bytes.

Setting the security key

```
NWK_SetSecurityKey((uint8_t *)"Security12345678");
```

5.2.9 Application Endpoints

In order to receive data, the application should register a data indication callback associated with the endpoint identifier. *NWK_OpenEndpoint()* function is used to register an endpoint. Endpoint identifier should be greater than *1* and less than *16*. Endpoint identifier 0 is reserved for the network layer command frames.

More than one endpoint can be open at the same time. This allows for implementation of the independent services running on the device virtually in parallel.

Section 5.4 further explains how to process received data.

Registering the endpoint indication callback

```
static bool appDataInd(NWK_DataInd_t *ind)
{
  // process the frame
  return true;
}

NWK_OpenEndpoint(1, appDataInd);
```

5.3 Sending the Data

In order to perform data transmission, the application first needs to create a data transmission request of *NWK_DataReq_t* type that specifies the data payload, data payload size, sets various transmission parameters, and defines the callback function to be executed to inform the application about the transmission results. The *NWK_DataReq()* function is used to send the data. Note that *NWK_DataReq()* must be called only once for the same *NWK_DataReq_t* structure until confirmation callback is called. Fields of the *NWK_DataReq_t* structure, accessible to the user, are listed in Table 5-1.

Table 5-1. Network Data Request Parameters

Name	Description
dstAddr	Network address of the destination device
dstEndpoint	Endpoint number on the destination device
srcEndpoint	Local endpoint number
options	Data request options. It may be any combination of the following constants listed in Table 5-2 (combined using bitwise OR operator “|”)
data	Pointer to the payload data
size	Size of the payload data
confirm	Pointer to the confirmation callback. It should have the following prototype: “void confirm(NWK_DataReq_t *req)”
status	This field is filled by the stack and can be accessed from the confirmation callback. It can have one of the values listed in Table 5-3
control	This field is filled by the stack and can be accessed from the confirmation callback. It contains a value from the Control field of the Acknowledgment Command frame

Table 5-2. Data Request Options

Name	Description
NWK_OPT_ACK_REQUEST	Request an acknowledgment
NWK_OPT_ENABLE_SECURITY	Encrypt the payload
NWK_OPT_BROADCAST_PAN_ID	Set destination PAN ID to 0xffff (broadcast)
NWK_OPT_LINK_LOCAL	Set a Link Local field in the Network Frame Control Field to 1
NWK_OPT_MULTICAST	Set a Multicast field in the Network Frame Control Field to 1 and send a message to a group indicated by the *dstAddr* field

Table 5-3. Data Request Status Codes

Name	Description
NWK_SUCCESS_STATUS	Operation completed successfully
NWK_ERROR_STATUS	Unknown error
NWK_OUT_OF_MEMORY_STATUS	Buffer allocation failed
NWK_NO_ACK_STATUS	Network level acknowledgment was not received
NWK_NO_ROUTE_STATUS	Route to the destination address was not found
NWK_PHY_CHANNEL_ACCESS_FAILURE_STATUS	Radio failed to gain access to the channel
NWK_PHY_NO_ACK_STATUS	Physical level acknowledgment was not received

Sending the data

```
static uint8_t message;
static NWK_DataReq_t nwkDataReq;

static void appDataConf(NWK_DataReq_t *req)
{
  if (NWK_SUCCESS_STATUS == req->status)
    // frame was sent successfully
  else
    // some error happened
}

static void sendFrame(void)
{
  nwkDataReq.dstAddr = 0;
  nwkDataReq.dstEndpoint = 1;
  nwkDataReq.srcEndpoint = 5;
  nwkDataReq.options = NWK_OPT_ACK_REQUEST | NWK_OPT_ENABLE_SECURITY;
  nwkDataReq.data = &message;
  nwkDataReq.size = sizeof(message);
  nwkDataReq.confirm = appDataConf;
  NWK_DataReq(&nwkDataReq);
}
```

5.4 Receiving the Data

If the application has registered a data indication callback, as described in Section 5.2.9, it will be able to receive data. When a frame is received and processed by the stack it is indicated to the application via a registered callback function. This function has the following prototype *"bool appDataInd(NWK_DataInd_t *ind)"*. Fields of the *NWK_DataInd_t* structure are described in Table 5-4. The callback function must return a Boolean value telling the stack whether to send an acknowledgment frame. This feature allows application data flow control.

Table 5-4. Network Data Indication Structure Fields

Name	Description
srcAddr	Network address of the source device
dstEndpoint	Destination endpoint number (local)
srcEndpoint	Source endpoint number (remote)
Options	Data indication options. It may be any combination of the constants listed in Table 5-5 (combined using bitwise OR operator "|")
Data	Pointer to the payload data
Size	Size of the payload data
Lqi	LQI of the received frame
Rssi	RSSI of the received frame

Table 5-5. Data Indication Options

Name	Description
NWK_IND_OPT_ACK_REQUESTED	Acknowledgment was requested
NWK_IND_OPT_SECURED	Frame was encrypted
NWK_IND_OPT_BROADCAST	Frame was sent to a broadcast address (0xffff)
NWK_IND_OPT_LOCAL	Frame was received from a directly accessible node
NWK_IND_OPT_BROADCAST_PAN_ID	Frame was sent to a broadcast PAN ID (0xffff)
NWK_IND_OPT_LINK_LOCAL	Frame was sent with a Link Local field set to 1
NWK_IND_OPT_MULTICAST	Frame was sent to a group address

The application can set 1 byte of data to be sent in the acknowledgment frame. This is done using the *NWK_SetAckControl()* function. This byte can be used to pass additional information to the sending side, for example a parent can tell a sleeping device not to sleep for a while, and wait for additional data.

Receiving the data

```
static bool appDataInd(NWK_DataInd_t *ind)
{
  if (!appReadyToReceive)
    return false;
  // process ind->size bytes of the data pointed by ind->data
  NWK_SetAckControl(APP_DO_NOT_SLEEP);
  return true;
}
```

5.5 Multicast Groups

The multicast groups API are represented by the following functions:

- NWK_GroupIsMember() – check if node is a member of a group
- NWK_GroupAdd() – add node to the group
- NWK_GroupRemove() – remove node from the group

Using multicast groups API

```
NWK_GroupAdd(0x1234);
if (NWK_GroupIsMember(0x1234))
{
  // Now node is a member of 0x1234
}
NWK_GroupRemove(0x1234);
// Node is no longer a member of the group
```

5.6 Routing Table Management

The Routing Table API is represented by the following functions:

- NWK_RouteFindEntry() – find an entry in the Routing Table matching requested destination address
- NWK_RouteNewEntry() – allocate a new entry in the Routing Table
- NWK_RouteFreeEntry() – free previously allocated entry
- NWK_RouteNextHop() – get a network address of the next hop node on a route to the requested destination
- NWK_RouteTable() – get a pointer to the entire Routing Table

Creating a static route

```
NWK_RouteTableEntry_t *entry;

entry = NWK_RouteNewEntry();
entry->fixed = 1;
entry->multicast = 0;
entry->score = 1;
entry->dstAddr = 5;
entry->nextHopAddr = 1;
```

5.7 Busy State Management

The network layer provides an API for the stack busy status management. This API is represented by the following functions:

- NWK_Lock() – increment the lock counter
- NWK_Unlock() – decrement the lock counter

A positive value of the lock counter will make *NWK_Busy()* return a true value. This behavior may be used to coordinate actions between the parts of the application and specifically between the service and the application running in parallel. *NWK_Lock()* and *NWK_Unlock()* must always be called in pairs and in this specific order.

Creating a static route

```
NWK_Lock();

// NWK_Busy() will return true until corresponding NWK_Lock() is called

NWK_Unock();

// NWK_Busy() will return false unless another lock is set by the stack or
// another part of the application
```

5.8 Network Layer Power Management

The network layer provides an API to manage the radio transceiver power state. This API is represented by the following functions:

- *NWK_Busy()* – check if stack is ready to sleep (no frames are being processed at the moment)
- *NWK_SleepReq()* – request to switch radio transceiver into sleep mode. This function should be called only if the *NWK_Busy()* function returned *true*. Radio transceiver is asleep at the function return; there is no special confirmation callback
- NWK_WakeupReq() – request to switch radio transceiver into active mode. Radio transceiver is awake at the function return; there is no special confirmation callback

Radio transceiver power management

```
case APP_STATE_PREPARE_TO_SLEEP:
{
  if (!NWK_Busy())
  {
    NWK_SleepReq();
    appState = APP_STATE_SLEEP;
  }
} break;

...

case APP_STATE_WAKEUP:
{
  NWK_WakeupReq();
  appState = APP_STATE_SEND;
} break;
```

5.9 System Services

5.9.1 Initialization and Task Scheduling

Before any Lightweight Mesh APIs can be used the system must be initialized. Initialization is done using the *SYS_Init()* function. This function also performs low level hardware initialization, so it is recommended to call this function as early as possible in the application.

Lightweight Mesh uses cooperative multitasking; in order to run stack internal tasks, the application must call the *SYS_TaskHandler()* function as often as possible. Generally this should be done from the main “while (1)” loop.

Typical use of SYS_init() and SYS_TaskHandler() functions

```
int main(void)
{
  SYS_Init();

  while (1)
  {
    SYS_TaskHandler();
  }
}
```

5.9.2 Software Timers

Lightweight Mesh system environment provides support for software timers. Software timers have a low hardware overhead (they all run from a single hardware timer) and the application can start any number of software timers.

A software timer is described by the *SYS_Timer_t* structure. Fields of this structure are described in Table 5-6.

Table 5-6. Software Timer Parameters

Name	Description
interval	Timer interval in milliseconds
mode	Timer operation mode. One of the following: • SYS_TIMER_INTERVAL_MODE – timer *handler* will be called once after *interval* milliseconds • SYS_TIMER_PERIODIC_MODE – timer *handler* will be called every *interval* milliseconds until stopped by the application
handler	Timer event handler. This function should have following prototype: “void handler(SYS_Timer_t *timer)”

Software timer API is represented by the following functions:

- *SYS_TimerStart()* – start a timer
- *SYS_TimerStop()* – stop a timer
- *SYS_TimerStarted()* – check if timer is started

Using software timers

```
static SYS_Timer_t appTimer;

static void appTimerHandler(SYS_Timer_t *timer)
{
  // handle timer event
  If (timeToStop)
    SYS_TimerStop(timer);
}

static void startTimer(void)
{
  appTimer.interval = 1000;
  appTimer.mode = SYS_TIMER_PERIODIC_MODE;
  appTimer.handler = appTimerHandler;
  SYS_TimerStart(&appTimer);
}
```

5.10 Advanced Transceiver Features

5.10.1 Random Number Generator

The random number generator can be enabled by defining PHY_ENABLE_RANDOM_NUMBER_GENERATOR in the configuration file. This setting only has an effect if the radio transceiver supports this feature.

A Random number can be requested using the *PHY_RandomReq()* function. A 16-bit random value is available immediately on return from the function.

Using the random number generator

```
void randomize(void)
{
  srand(PHY_RandomReq());
}
```

5.10.2 Energy Detection Measurement

An energy detection measurement can be enabled by defining PHY_ENABLE_ENERGY_DETECTION in the configuration file. This feature is available on all radio transceivers.

A channel energy measurement can be requested using the *PHY_EdReq()* function. The measured channel energy value (in dB) is available immediately on return from the function.

Using energy detection

```
void scanChannelEnergy(void)
{
  int8_t ed;

  PHY_SetChannel(0x0d);
  ed = PHY_EdReq();

  if (ed < -50)
    // stay on this channel
  else
    // scan another channel
}
```

5.11 Configuration Parameters

Every application should provide a file named *config.h*. This file should contain any overrides of the default parameters, and it may be empty. It is also recommended that application parameters are stored in this file with prefix *APP_*. A complete list of Lightweight Mesh stack configuration parameters and their description's are provided below.

- NWK_BUFFERS_AMOUNT – Number of buffers reserved for stack operation. These buffers are used to send, receive, and route frames. The minimum useful value is 1; this will allow the stack to send and receive frames. However, sending a frame with an acknowledgment request requires two buffers – one to send a frame and another to receive an acknowledgment. The minimum recommended value is 3
- NWK_DUPLICATE_REJECTION_TABLE_SIZE – number of entries in the duplicate rejection table. This table is used to detect and reject frames that already have been received and processed by the stack. This table is used to resolve:
  - Loops in the network topology. Sometimes the routing algorithm may create a situation where a frame is routed in a loop between a few nodes
  - Already processed broadcast frames, received from the neighboring nodes

  Entries in this table remain active for NWK_DUPLICATE_REJECTION_TTL milliseconds and are never replaced before this timeout, so when a frame is received and there are no free entries in the duplicate rejection table, the frame will not be processed
- NWK_DUPLICATE_REJECTION_TTL – duplicate rejection table entry life time (in milliseconds). This parameter should be set to at least the maximum anticipated frame propagation time across the network, multiplied by two
- NWK_ROUTE_TABLE_SIZE – number of entries in the Routing Table. Each entry contains a next hop address for the destination network address. It is recommended to set this parameter to the expected number of nodes in the network, but if it is impossible (due to memory constraints, for example) then this parameter should be set as high as possible
- NWK_ROUTE_DEFAULT_SCORE – default score assigned to a new entry in the Routing Table. This score defines how many failed attempts to use this route will be performed, before this entry is removed from the routing table. Routing algorithm is further described in Section 4.3
- NWK_ACK_WAIT_TIME – network acknowledgment wait time (in milliseconds). After this timeout expires, request to send data is confirmed with the status of NWK_NO_ACK_STATUS. Generally this parameter should be set to at least the maximum anticipated frame propagation time across the network, multiplied by two. But it can be reduced in some cases

- NWK_GROUPS_AMOUNT – number of groups this node can be a part of
- NWK_ROUTE_DISCOVERY_TABLE_SIZE – number of entries in the Route Discovery Table. This parameter defines how many simultaneous route discovery requests node can support
- NWK_ROUTE_DISCOVERY_TIMEOUT – lifetime of an entry in the Route Discovery Table
- NWK_ENABLE_ROUTING – if defined, will enable support for routing on the network layer. Disabling routing for nodes that are not expected to route data (sleepy devices, for example) helps to reduce memory footprint
- NWK_ENABLE_SECURITY – if defined, will enable support for data encryption on the network layer. See also SYS_SECURITY_MODE
- NWK_ENABLE_MULTICAST – if defined, will enable support for multicast messages
- NWK_ENABLE_ROUTE_DISCOVERY – if defined, will enable support for AODV route discovery process. NWK_ENABLE_ROUTING must be defined as well for this parameter to have any effect
- NWK_ENABLE_SECURE_COMMANDS – if defined, will enable security for all internal network layer commands
- SYS_SECURITY_MODE – selects encryption algorithm if NWK_ENABLE_SECURITY is defined. Possible values are:
  - 0 – Hardware accelerated AES-128 (only on platforms with hardware AES engine)
  - 1 – Software XTEA (all platforms)
- PHY_ENABLE_ENERGY_DETECTION – if defined, will enable energy detection API in the PHY layer
- PHY_ENABLE_RANDOM_NUMBER_GENERATOR – if defined, will enable true random number generation API in the PHY layer

6. References and Suggested Literature

[1] IEEE Std 802.15.4-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs).
[2] Atmel AVR2050: Atmel BitCloud® Developer Guide.
[3] AT86RF212 Complete Datasheet.
[4] Atmel AVR2131: Lightweight Mesh Getting Started Guide.

7. Revision History

Doc. Rev.	Date	Comments
42028G	03/2014	Removed the list of supported platforms and referenced to the Lightweight Mesh Getting Started Guide the list of supported platforms
42028F	03/2014	Extended list of supported platforms Added busy state management API information Modified miscellaneous PHY API information
42028E	08/2013	Added ATSAMD20 information Changed product line abbreviation from AVR to Wireless in the document footer
42028D	05/2013	Added API description for AODV route discovery and multicast messages
42028C	03/2013	ATmega256RFR2-XPLD has been replaced by ATmega256RFR2-XPRO
42028B	02/2013	Added ATmega256RFR2 information
42028A	09/2012	Initial document release

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