TTC標準
Standard

JJ-300.10

Home network Communication Interface for ECHONET Lite
(IEEE 802.15.4/4e/4g　920MHz-band Wireless)

Edition 2.2

Established on March 11, 2015

THE TELECOMMUNICATION TECHNOLOGY COMMITTEE

TTC Telecommunication Technology Committee

Table of Contents

<Reference>

1. Relation with international recommendations and others

International standards and others related to this standard are described in this document.

2. Items added to the above international recommendations and others

Optional selection items involved with international standards related to this standard, items added to these standards, and changes to them for Japanese domestic specifications are described in this document.

3. Revision history

Version	Date	Description
1	February 21, 2013	Established
2	February 20, 2014	Specifications related to system A have been added (Sections 5.6 Security configuration, 5.7 Frame formats, and 5.9 Recommended specification for single-hop smart meter-HEMS communication have been added, and other additions have been made.)
2.1	May 22, 2014	In terms with system B, parameter values have been modified according to the revision of the ZigBee IP specification. (The description in Sections 6.6.1, 6.6.2, 6.6.3, 6.7, and 6.7.3, and Table 6-29 (Table 6-31 in the older version) has been modified, and Table 6-34 in the older version has been deleted.)
2.2	March 11, 2015	Typos are corrected. (5.9.3.2.1 (3), 5.9.3.2.4 (4), 6.2.10.1, 6.3.5.1 11, 6.3.8.4)

4. Industrial property rights

Information regarding submission of "IPR Licensing Statements" concerned with this standard is available on the TTC website.

5. Others

(1) Main referenced recommendations and standards

Described in this document.

6. Working group developing this standard

Version 1: TTC Next-generation Home Network Systems Working Group

Version 2: TTC Next-generation Home Network Systems Working Group

Version 2.1: TTC Next-generation Home Network Systems Working Group

Version 2.2: TTC Next-generation Home Network Systems Working Group

1. Overview of This Standard

This standard defines the specifications for protocols for constructing a home network to implement remote control, monitoring, and other functions for home electric appliances using ECHONET Lite protocol [EL] and [ELOBJ] that are related to 920MHz-specific low-power radio communications.

2. Items Specified by This Standard

2.1. Scope

To use ECHONET Lite for a 920MHz-band wireless (IEEE 802.15.4/4e/4g) network, there are the following options:

a. Use IPv6 and 6LoWPAN as network layer protocols.

b. Directly contain ECHONET Lite payload in IEEE 802.15.4 frames.

Table 2-1: 920MHz-band wireless

<table>
<tr><th>Protocol stack</th><th colspan="3">Protocol(s) and specification(s)</th></tr>
<tr><td>Session to application layers</td><td colspan="2">ECHONET Lite</td><td rowspan="3">b. ECHONET Lite
on Layer2 frames</td></tr>
<tr><td>Transport layer</td><td>UDP</td><td>TCP</td></tr>
<tr><td>Network layer</td><td colspan="2">a. IPv6 / 6LoWPAN</td></tr>
<tr><td>Data link layer</td><td colspan="3">IEEE 802.15.4, IEEE 802.15.4e/g</td></tr>
<tr><td>Physical layer</td><td colspan="3">IEEE 802.15.4, IEEE 802.15.4g</td></tr>
<tr><td>Media</td><td colspan="3">Radio wave (920MHz band)</td></tr>
</table>

The scope of this standard is a and b. For a, there are two systems: Systems A and B, and for b, there is one system: System C.

2.2. Overview of each system

This standard specifies the following three systems.

Table 2-2: Three systems specified by this standard

<table>
<tr><th>System</th><th>Option in Table 1</th><th colspan="2">Related organizations</th></tr>
<tr><td>System A</td><td>a</td><td rowspan="3">ECHONET Consortium</td><td>Wi-SUN Alliance</td></tr>
<tr><td>System B</td><td>a</td><td>ZigBee Alliance</td></tr>
<tr><td>System C</td><td>b</td><td>Wi-SUN Alliance</td></tr>
</table>

In systems A and B, the IPv6/6LoWPAN and UDP layer (and TCP layer as an option) are provided on the physical layer and data link layer (IEEE 802.15.4/4e/4g) and ECHONET Lite payload is contained in them. System A provides a single-hop function. System B provides a multihop function in addition to a single-hop function.

In system C, ECHONET Lite payload is directly contained in the physical layer and data link layer (IEEE 802.15.4/4e/4g). System C provides a single-hop function and no multihop function.

3. Reference Standards and Documents

The following lists the standards that contain some specifications defined in this standard and related standards.

If any reference standard or document is revised, the application of the latest revised version for implementation based on this standard is recommended. This rule may not apply to other reference standards.

[6LOWPAN]	Transmission of IPv6 Packets over IEEE 802.15.4 Networks (6LoWPAN), IETF RFC 4944
[6LPHC]	Compression Format for IPv6 Datagrams in 6LoWPAN Networks, IETF RFC 6282
[6LPND]	Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs), IETF RFC 6775
[802.15.4]	IEEE Std. 802.15.4 - 2011™ , IEEE Standard for Information Technology - Telecommunications and Information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), September 2011
[802.15.4e]	IEEE Std. 802.15.4e-2012™ , Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) - Amendment 1: MAC sub-layer, April 2012.
[802.15.4g]	IEEE Std. 802.15.4g-2012™ , Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) - Amendment 3: Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks, April 2012.
[T108]	ARIB STD-T108 920MHz-Band Telemeter, Telecontrol, and Data Transmission Radio Equipment
[AES-CCM]	NIST SP800-38C
[AES-GCM]	NIST SP800-38D
[AH]	IP Authentication Header, IETF RFC 4302
[CMAC]	NIST SP800-38B
[EL]	The ECHONET Lite Specification Version 1.01
[ELOBJ]	ECHONET Specification APPENDIX: Detailed Requirements for ECHONET Device Objects Release B
[EAP]	Extensible Authentication Protocol (EAP), IETF RFC 3748
[EAP-PSK]	The EAP-PSK Protocol: A Pre-Shared Key Extensible Authentication Protocol (EAP) Method, IETF RFC 4764
[EAP-TLS]	The EAP-TLS Authentication Protocol, IETF RFC 5216
[ESP]	IP Encapsulating Security Payload (ESP), IETF RFC 4303
[HMAC-SHA256]	Using HMAC-SHA-256, HMAC-SHA-384, and HMAC-SHA-512 with IPsec, IETF RFC 4868
[IPv6]	Internet Protocol, Version 6 (IPv6) Specification, IETF RFC 2460

[IPv6-DHCP] "IPv6 Prefix Options for Dynamic Host Configuration Protocol (DHCP) version 6, IETF RFC 3633

[IPv6-MIB] Management Information Base for IP Version 6: ICMPv6 Group, IETF RFC 2466

[IPv6-RH] Deprecation of Type 0 Routing Headers in IPv6, IETF RFC 5095

[IPv6-SAA] IPv6 Stateless Address Autoconfiguration, IETF RFC 2462

[ICMP6] Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification, IETF RFC 4443

[IP6ADDR] IP Version 6 Addressing Architecture, IETF RFC 4291

[MLE] Mesh Link Establishment, IETF draft-kelsey-intarea-mesh-link-establishment-03

[NAI] The Network Access Identifier, IETF RFC 4282

[ND] Neighbor Discovery for IP version 6 (IPv6), IETF RFC 4861

[PANA] Protocol for Carrying Authentication for Network Access (PANA), IETF RFC 5191

[PANA-RELAY] Protocol for Carrying Authentication for Network Access (PANA) Relay Element, IETF RFC 6345

[PANA-ENC] Encrypting PANA AVPs, IETF RFC 6786

[RPL] RPL: IPv6 Routing Protocol for Low power and Lossy Networks, IETF RFC 6550

[RPL-HDR] An IPv6 Routing Header for Source Routes with RPL, IETF RFC 6554

[RPL-OPT] RPL Option for Carrying RPL Information in Data-Plane Datagrams, IETF RFC 6553

[RPL-MRHOF] The Minimum Rank with Hystersis Objective Function, IETF RFC 6719

[SE-TRD] ZigBee document 095449, ZigBee Smart Energy Profile 2.0 Technical Requirements

[SLAAC] IPv6 Stateless Address Autoconfiguration, IETF RFC 4862

[SMHEMSIF] ECHONET CONSORTIUM, Interface Specification for Application Layer Communication between Smart Electric Energy Meters and HEMS Controllers Version 1.00

[TCP] Transmission Control Protocol (TCP), IETF RFC 793 [TLS]The Transport Layer Security (TLS) Protocol Version 1.2, IETF RFC 5246

[TLS-PSK] Pre-Shared Key Cipher suites for Transport Layer Security (TLS), IETF RFC 4279

[TLS-ECC] Elliptic Curve Cryptography (ECC) Cipher Suites for Transport Layer Security (TLS), IETF RFC 4492

[TLS-AEAD] An Interface and Algorithms for Authenticated Encryption, IETF RFC 5116

[TLS-GCM] AES Galois Counter Mode (GCM) Cipher Suites for TLS, IETF RFC 5288

[TLS-PSK-GCM] Pre-Shared Key Cipher Suites for TLS with SHA-256/384 and AES Galois Counter Mode, IETF RFC 5487

[TLS-ECC-GCM] TLS Elliptic Curve Cipher Suites with SHA-256/384 and AES Galois Counter Mode

(GCM), IETF RFC 5289

[TLS-CCM] AES-CCM Cipher Suites for TLS, IETF draft-mcgrew-tls-aes-ccm-04

[TLS-ECC-CCM] AES-CCM ECC Cipher Suites for TLS, IETF draft-mcgrew-tls-aes-ccm-ecc-02

[TTC TR-1043] Implementation guidelines of Home network communication interface

[TRKL-MCAST] Multicast Forwarding Using Trickle, IETF draft-ietf-roll-trickle-mcast-00

[UDP] User Datagram Protocol (UDP), IETF RFC 768

[ULA] Unique Local IPv6 Unicast Addresses, IETF RFC 4193

[Wi-SUN-PHY] Wi-SUN PHY specification document for ECHONET Lite, 20120212-PHYWG-Echonet-Profile-0v01

[Wi-SUN-MAC] WI-SUN MAC specification document for ECHONET Lite, 20120212-MACWG-Echonet-Profile-0v01

[Wi-SUN-IF] WI-SUN Interface specification document for ECHONET Lite, 20131023-Wi-SUN-Echonet-Profile-2v01

[Wi-SUN-CTEST] Wi-SUN conformance test specification for ECHONET Lite

[Wi-SUN-ITEST] Wi-SUN interoperability test specification for ECHONET Lite

[ZIP] ZigBee Internet Protocol Specification 1.0, ZigBee Alliance Document

4. Terms and Acronyms

4.1. Terms

6LBR

As defined in [6LPND].

6LR

As defined in [6LPND].

Authentication Server

The server implementation that is in charge of verifying the credentials of a PaC that is requesting the network access service. The AS receives a request from the PAA and responds with the result of verification instead of the PaC. This server completes the EAP and EAP methods. The AS may be on the node on which the PAA resides, on a dedicated node on the access network, or on a central server in the Internet.

Border router

A router node that forwards packets not addressed to itself, but to a different routing domain.

Coordinator

A node that is responsible for starting and maintaining a network consisting of nodes specified by this standard. This node is a PAN coordinator specified in [802.15.4]. The node may not have an IP-level router function. It may also be called a "parent device". Unlike a coordinator specified in [802.15.4], this coordinator means a node that has a controller function for the entire system, not only for the data link layer.

Enforcement point

The access control implementation that is in charge of allowing access (data traffic) of authorized clients while preventing access by others.

Global address

As defined in [SLAAC].

Link local address

As defined in [SLAAC].

Host

Any node that is neither a coordinator nor a router. The node may also be called a "child device".

Node

A node that implements the protocols specified by this standard.

PAN

Personal area network. See [802.15.4].

Router

A node that forwards network layer packets not addressed to itself.

RPL

An IPv6 routing protocol specified in IETF RFC 6550.

RPL instance

As defined in [RPL].

RPL root

As defined in [RPL].

ZIP

Abbreviation for ZigBee IP.

ZIP coordinator

A ZigBee IP node that is responsible for starting and maintaining a ZigBee IP network. This node implements the functionalities of a MAC PAN coordinator, 6LoWPAN LBR root, PANA authentication agent, and EAP server.

ZIP router

A ZigBee IP node that forwards network layer packets not addressed to itself.

ZIP host

Any ZigBee IP node that is not a ZIP router.

ZIP node

A device that implements the protocol suite specified by this standard.

Single hop

A configuration in which there is no packet forwarding by a relay and a transmitter directly communicates with a receiver.

Multihop

A configuration in which there may be a router between a transmitter and receiver, and the router may perform packet forwarding.

4.2. Acronyms

AES	Advanced Encryption Standard
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
DAD	Duplicate address detection. An algorithm used to ensure the uniqueness of an address in an IP network. See [6LPND]
DAG	Directed Acyclic Graph. See [RPL]
DODAG	Destination Oriented DAG. See [RPL]
EAP	Extensible Authentication Protocol. See [EAP]
EUI	Extended Unique Identifier. See [802.15.4]
FFD	Full Function Device. See [802.15.4]
ETX	Expected Transmission Count. See RFC 6551
IETF	Internet Engineering Task Force
IEEE	Institute of Electrical and Electronic Engineers
MAC	Medium Access Control
OCP	Objective Code Point. See [RPL]
OF	Objective Function. See [RPL]
ND	Neighbor Discovery
PAA	PANA Authentication Agent. See [PANA]
PaC	PANA Client. See [PANA]
PRE	PANA Relay Element. See [PANA-RELAY]
RFD	Reduced Function Device [802.15.4]
ULA	Unique Local Address. See RFC 4193
UDP	User Datagram Protocol [UDP]

4.3. Definition of expression

The key words "must", "shall", "must not", "shall not", "required", "should", "should not", "may" and others are to

be interpreted as defined in RFC 2119.

5. System A

5.1. Overview

This chapter defines the physical layer part, data link layer part, and interface part that are required for ECHONET Lite communication between a coordinator and host using IP and IEEE 802.15.4/4e/4g (Sections 5.3, 5.4, and 5.5) and specifies the recommended specification for configuring a single-hop network using EHONET Lite (Section 5.8).

The physical and data link layer parts are composed of selected functions specified in the IEEE 802.15.4/4e/4g standard. The interface part is mainly composed of the adaptation, network, and transport layers. The part transmits transmission data from the ECHONET Lite application part to the destination device using the data link and physical layers and transmits reception data from the destination device to the ECHONET Lite application part. **Figure 5-1** shows the location of each part. In this chapter, "M" means a mandatory function in standards [802.15.4], [802.15.4e], and [802.15.4g], "O" means an optional function, "Y" means a function required for operating ECHONET Lite, and "N" means a function not required. Specifications and procedures for certification and interoperability tests are provided by [Wi-SUN-PHY], [Wi-SUN-MAC], [Wi-SUN-IF], [Wi-SUN-CTEST], and [Wi-SUN-ITEST].

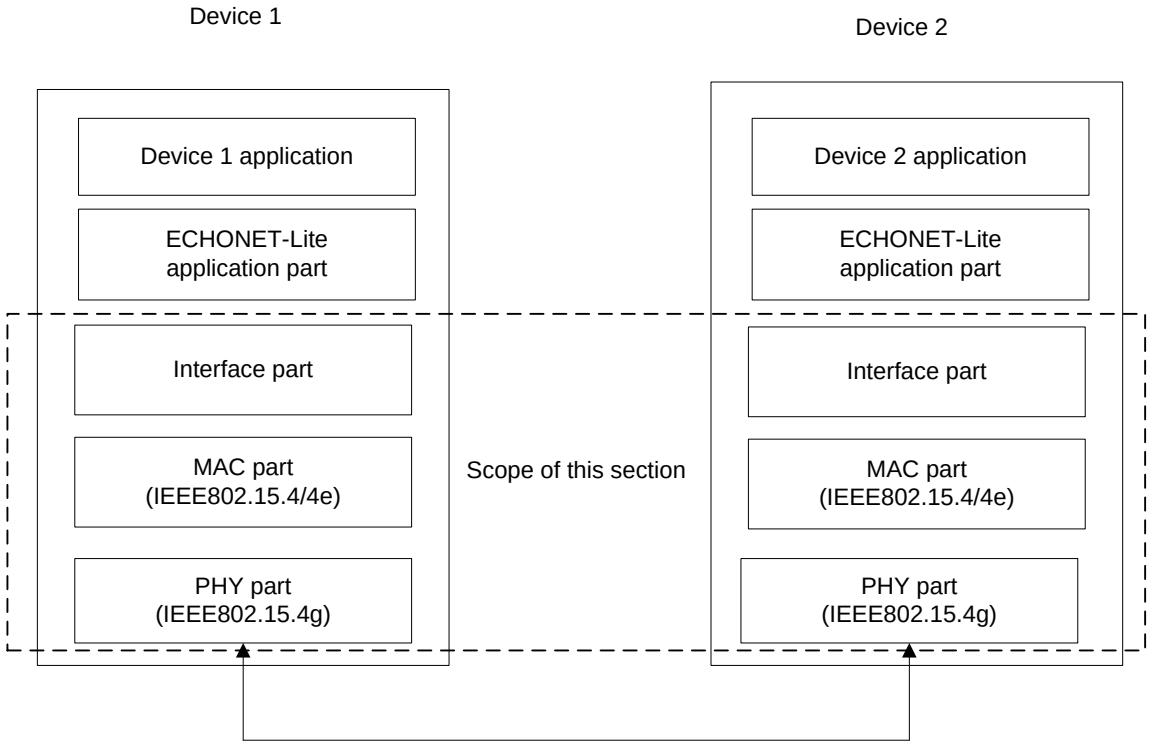


Figure 5-1: Scope defined by this chapter

5.2. Protocol stack

The protocol stack for a node specified for this system is shown in **Figure 5-2**.

The physical layer provides the following service as far as it is used in this system:

- Up-to-2047-octet PSDU exchange (Note that the system recommends 255 octets or less as described below.)

The data link layer provides the following services as far as it is used in this system:

- Discovery of an IEEE 802.15.4 PAN in radio propagation range
- Support of low-energy hosts that can change its status between sleep and active states
- Security functions that include encryption, manipulation detection, and replay attack protection (Note that key management is not performed by this layer.)

The 6LoWPAN adaptation layer provides the following services as far as it is used in this system:

- IPv6 and UDP header compression and decompression
- Fragmentation and reassembly of an IPv6 packet that exceeds the maximum payload size available in the data link layer frame
- Neighbor discovery (not necessary when done by the network layer)

The network layer provides the following services as far as it is used in this system:

- IPv6 address management and packet framing
- Neighbor discovery (not necessary when done by the adaptation layer)
- IPv6 stateless address autoconfiguration and duplicate address detection (DAD)
- IPv6 packet forwarding
- ICMPv6 messaging
- IPv6 packet multicast transmission and reception

The transport layer provides the following service as far as it is used in this system:

- Packet delivery that is not guaranteed by UDP

The application layer provides the following services:

- Detection of functional units (ECHONET objects) employed by the other nodes in the network
- Acquisition of parameters and statuses (ECHONET properties) the other nodes have
- Configuration of parameters and statuses for the other nodes
- Notification of parameters and statuses the local node has

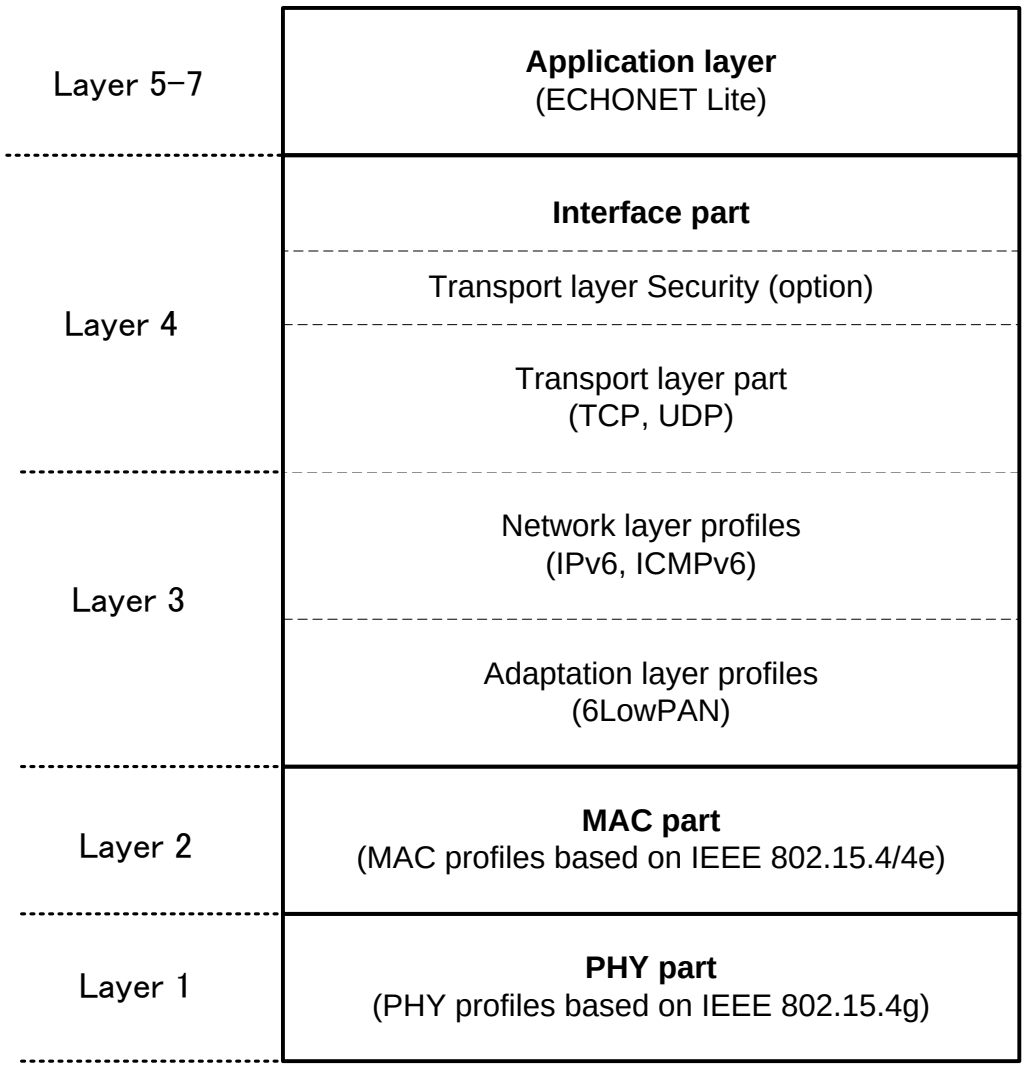


Figure 5-2: Layer structure defined by this chapter

5.3. Physical layer part

5.3.1. Overview

This chapter defines the PHY profiles configuring the physical layer part required for implementation for supporting ECHONET Lite. The profiles are based on features and capabilities defined in standards [802.15.4] and [802.15.4g]. For each profile, the corresponding chapter or section in standard [802.15.4] or [802.15.4g] is given.

5.3.2. PHY profiles

5.3.2.1. PLF/PLP capabilities

The requirements for the PHY Layer Function (PLF) and PHY Layer Packet (PLP) are described in **Table 5-1**.

Table 5-1: PLF/PLP capabilities

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
PLF1	Energy detection (ED)	[802.15.4] 8.2.5	FD1: M	FD1: Y
PLF2	Link quality indication (LQI)	[802.15.4] 8.2.6	M	Y
PLF3	Channel selection	[802.15.4] 8.1.2	M	Y
PLF4	Clear channel assessment (CCA)	[802.15.4] 8.2.7	M	Y
PLF4.1	Mode 1	[802.15.4] 8.2.7	O.2	Y
PLF4.2	Mode 2	[802.15.4] 8.2.7	O.2	N
PLF4.3	Mode 3	[802.15.4] 8.2.7	O.2	N
PLP1	PSDU size up to 2047 octets	[802.15.4g] 9.2	FD8: M	Y

5.3.2.2. RF capabilities

The requirements for the RF capabilities are described in **Table 5-2**.

Table 5-2: RF capabilities

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
RF12	SUN PHYs			
RF12.1	MR-FSK	[802.15.4g] 18.1	FD8: M	Y(*1)
RF12.2	MR-OFDM	[802.15.4g] 18.2	FD8: O	N
RF12.3	MR-O-QPSK	[802.15.4g] 18.3	FD8: O	N
RF12.4	MR-FSK-Generic PHY	[802.15.4g] 8.1.2, 10.2	RF12.1: O	N
RF12.5	Transmit and receive using CSM	[802.15.4g] 8.1a	M	Y
RF12.6	At least one of the bands given in Table 66 [802.15.4g]	[802.15.4g] 8.1	FD8: M	Y (920 MHz*2)
RF13	SUN PHY operating modes			
RF13.4	Operating mode #1 and #2 in 920 MHz or 950 MHz band	[802.15.4g] 18.1	FD8: M	Y
RF 13.5	Operating mode #3 and #4 in 920 MHz band	[802.15.4g] 18.1	FD8: O	N
RF14	MR-FSK Options			
RF14.1	MR-FSK FEC	[802.15.4g] 18.1.2.4	O	N
RF14.2	MR-FSK interleaving	[802.15.4g] 18.1.2.5	O	N
RF14.3	MR-FSK data whitening	[802.15.4g] 18.1.3	O	Y
RF14.4	MR-FSK mode switching	[802.15.4g] 18.1.4	O	N

*1: The frequency tolerance requirements in [802.15.4g] 18.1.5.3 do not apply. The frequency tolerance shall be +-20ppm.

*2: All channels shown in [802.15.4g] Table 68d within the supported operating mode(s) for the respective band shall be supported.

5.4. Data link layer (MAC) part

5.4.1. Overview

A node that has the coordinator functions defined for this system functions as an FFD defined in [802.15.4]. This section defines the MAC profiles configuring the MAC part based on 15.4 and 15.4e. The capabilities are generated from standards [802.15.4] and [802.15.4e], and summarized in tables.

Nodes for this system employ the 64-bit MAC-level addressing mode defined by [802.15.4]. A 64-bit EUI-64 address shall be stably allocated to each device when manufactured. This address is globally unique and is expected to be permanently stable for the device.

Section 5.4.2 defines the requirements in the beacon mode. Section 5.4.3 defines the requirements in the non-beacon mode. Either of those two modes shall be implemented as the data link layer profile.

5.4.2. Beacon mode profile

This section defines the Wi-SUN 15.4/4e MAC profiles for ECHONET Lite when the beacon mode is employed.

5.4.2.1. Functional device (FD) types

The requirements for the functional device types are described in **Table 5-3**.

Table 5-3: Functional device types

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
FD1	FFD	[802.15.4] 5.1	O.1	O.1
FD2	RFD	[802.15.4] 5.1	O.1	O.1
FD3	Support of 64 bit IEEE address	[802.15.4] 5.2.1.1.6	M	Y
FD4	Assignment of short network address (16 bit)	[802.15.4] 5.1.3.1	FD1: M	FD1: Y
FD5	Support of short network address (16 bit)	[802.15.4] 5.2.1.1.6	M	Y
FD8	SUN PHY device	[802.15.4g] 8.1	O.2	Y (#1)

O.1: Optional but at least one of the features described in FD1 and FD2 is required to be implemented

O.2: At least one of these features is supported

#1 MR-FSK is employed.

5.4.2.2. Main capabilities for the MAC sub-layer

This section describes the major capabilities for the MAC sub-layer.

5.4.2.3. MAC sub-layer functions

The requirements for the MAC sub-layer functions are described in **Table 5-4**.

Table 5-4: MAC sub-layer functions

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
MLF1	Transmission of data	[802.15.4] 6.3	M	Y
MLF1.1	Purge data	[802.15.4] 6.3.4, 6.3.5	FD1: M FD2: O	FD1: Y FD2: N
MLF2	Reception of data	[802.15.4] 6.3	M	Y
MLF2.1	Promiscuous mode	[802.15.4] 5.1.6.5	FD1: M FD2: O	FD1: Y FD2: N
MLF2.2	Control of PHY receiver	[802.15.4] 6.2.9	O	N
MLF2.3	Timestamp of incoming data	[802.15.4] 6.3.2	O	N
MLF3	Beacon management	[802.15.4] 5	M	Y
MLF3.1	Transmit beacons	[802.15.4] 5, 5.1.2.4	FD1: M FD2: O	FD1: Y FD2: N
MLF3.2	Receive beacons	[802.15.4] 5, 6.2.4	M	Y
MLF4	Channel access mechanism	[802.15.4] 5, 5.1.1	M	Y
MLF5	Guaranteed time slot (GTS) management	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF5.1	GTS management (allocation)	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF5.2	GTS management (request)	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF6	Frame validation	[802.15.4] 6.3.3, 5.2, 5.1.6.2	M	Y
MLF7	Acknowledged frame delivery	[802.15.4] 5, 6.3.3, 5.2.1.1.4, 5.1.6.4	M	Y
MLF8	Association and disassociation	[802.15.4] 5, 6.2.2, 6.2.3, 5.1.3	M	Y
MLF9	Security	[802.15.4] 7	M	Y
MLF9.1	Unsecured mode	[802.15.4] 7	M	Y
MLF9.2	Secured mode	[802.15.4] 7	O	Y
MLF9.2.1	Data encryption	[802.15.4] 7	O.4	Y
MLF 9.2.2	Frame integrity	[802.15.4] 7	O.4	Y

MLF10.1	ED	[802.15.4] 5.1.2.1, 5.1.2.1.1	FD1: M FD2: O	FD1: Y FD2: N
MLF10.2	Active scanning	[802.15.4] 5.1.2.1.2	FD1: M FD2: O	FD1: Y FD2: Y
MLF10.3	Passive scanning	[802.15.4] 5.1.2.1.2	M	Y
MLF10.4	Orphan scanning	[802.15.4] 5.1.2.1, 5.1.2.1.3	M	Y
MLF11	Control/define/determine/declare superframe structure	[802.15.4] 5.1.1.1	FD1: O	FD1: O
MLF12	Follow/use superframe structure	[802.15.4] 5.1.1.1	O	Y
MLF13	Store one transaction	[802.15.4] 5.1.5	FD1: M	FD1: Y
MLF14	Ranging	[802.15.4] 5.1.8	RF4: O	N
MLF14.1	DPS	[802.15.4] 5.1.8.3, 6.2.15	O	N
MLF15(4g)	MPM for all coordinators when operating at more than 1% duty cycle	[802.15.4g] 5.1.13	M	FD8: Y
MLF15	TSCH Capability	[802.15.4e] Table 8a	O	N
MLF16	LL Capability	[802.15.4e] Table 8b	O	N
MLF17	DSME Capability	[802.15.4e] 6.2, Table 8c	O	N
MLF18	EBR capability	[802.15.4e] 5.3.12	O	Y
MLF18.1	EBR commands	[802.15.4e] 5.3.7	MLF18: O	Y
MLF18.1.1	EBR Enhanced Beacon request command	[802.15.4e] 5.3.7.2	FD1: M FD2: O	FD1: Y FD2: Y
MLF19	LE capability	[802.15.4e] 5.1.1.7, 5.1.11	O	O (#1)
MLF19.1	LE specific MAC sub-layer service specification	[802.15.4e] 6.4.3.7	MLF19: M	MLF19: Y
MLF19.2	Coordinated Sampled Listening (CSL) capability	[802.15.4e] 5.1.11.1	MLF19: O.1	N
MLF19.3	Receiver Initiated Transmission (RIT) capability	[802.15.4e] 5.1.11.2	MLF19: O.1	N
MLF19.4	LE superframe	[802.15.4e] 5.1.1.7.1, 5.1.1.7.2, 5.1.1.7.3	MLF19: O.1	MLF19: Y

MLF19.5	LE-multipurpose Wake-up frame	[802.15.4e] 5.2.2.8	MLF19.2: M	N
MLF19.6	LE, CSL Information Element	[802.15.4e] 5.2.4.7	MLF19.2: M	N
MLF19.7	LE RIT Information Element	[802.15.4e] 5.2.4.8	MLF19.3: O	N
MLF19.8	LE-commands	[802.15.4e] 5.3.12	MLF19.3: M	N
MLF20	MAC Metrics PIB Attributes	[802.15.4e] 6.4.3.9	O	N
MLF21	FastA commands	[802.15.4e] 5.1.3.3	O	N
MLF23	Channel Hopping	[802.15.4e] Table 52f	O	N
MLF23.1	Hopping IEs	[802.15.4e] 5.2.4.16, 5.2.4.17	MLF18: M	N

O.1: Optional but at least one of the features described in FD1 and FD2 is required to be implemented

O.4: At least one of these features shall be supported.

#1: Implementation is optional.

5.4.2.3.1. MAC frames

The requirements for the MAC frames are described in **Table 5-5**.

Table 5-5: MAC frames

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)		Support (Y: Yes, N: No, O: Option)
			Transmitter	Receiver	
MF1	Beacon	[802.15.4] 5.2.2.1	FD1: M	M	Y
MF2	Data	[802.15.4] 5.2.2.2	M	M	Y
MF3	Acknowledgment	[802.15.4] 5.2.2.3	M	M	Y
MF4	Command	[802.15.4] 5.2.2.4	M	M	Y
MF4.1	Association request	[802.15.4] 5.2.2.4, 5.3.1	M	FD1: M	Y
MF4.2	Association response	[802.15.4] 5.2.2.4, 5.3.2	FD1: M	M	Y
MF4.3	Disassociation notification	[802.15.4] 5.2.2.4, 5.3.3	M	M	Y
MF4.4	Data request	[802.15.4] 5.2.2.4, 5.3.4	M	FD1: M	Y
MF4.5	PAN identifier conflict notification	[802.15.4] 5.2.2.4, 5.3.5	M	FD1: M	Y
MF4.6	Orphaned device notification	[802.15.4] 5.2.2.4, 5.3.6	M	FD1: M	Y
MF4.7	Beacon request	[802.15.4] 5.2.2.4, 5.3.7	FD1: M	FD1: M	Y
MF4.8	Coordinator realignment	[802.15.4] 5.2.2.4, 5.3.8	FD1: M	M	Y
MF4.9	GTS request	[802.15.4] 5.2.2.4, 5.3.9	MLF5: O	MLF5: O	N
MF5	4-octet FCS	[802.15.4g] 5.2.1.9	FD8: M	FD8: M	FD8: Y

5.4.3. Non-beacon mode profile

This section defines the Wi-SUN 15.4/4e MAC profiles for ECHONET Lite when the non-beacon mode is employed.

5.4.3.1. Functional device (FD) types

The requirements for the functional device types are described in **Table 5-6**.

Table 5-6: Functional device types

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
FD1	FFD	[802.15.4] 5.1	O.1	O.1
FD2	RFD	[802.15.4] 5.1	O.1	O.1
FD3	Support of 64 bit IEEE address	[802.15.4] 5.2.1.1.6	M	Y
FD4	Assignment of short network address (16 bit)	[802.15.4] 5.1.3.1	FD1: M	FD1: Y
FD5	Support of short network address (16 bit)	[802.15.4] 5.2.1.1.6	M	Y
FD8	SUN PHY device	[802.15.4g] 8.1	O.2	Y (#1)

O.1: Optional but at least one of the features described in FD1 and FD2 is required to be implemented

O.2: At least one of these features is supported

#1: MR-FSK is employed.

5.4.3.2. Major capabilities for the MAC sub-layer

This section describes the major capabilities for the MAC sub-layer.

5.4.3.2.1. MAC sub-layer functions

The requirements for the MAC sub-layer functions are described in **Table 5-7**.

Table 5-7: MAC sub-layer functions

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)	Support (Y: Yes, N: No, O: Option)
MLF1	Transmission of data	[802.15.4] 6.3	M	Y
MLF1.1	Purge data	[802.15.4] 6.3.4, 6.3.5	FD1: M FD2: O	FD1: Y FD2: N
MLF2	Reception of data	[802.15.4] 6.3	M	Y
MLF2.1	Promiscuous mode	[802.15.4] 5.1.6.5	FD1: M FD2: O	FD1: Y FD2: N
MLF2.2	Control of PHY receiver	[802.15.4] 6.2.9	O	O
MLF2.3	Timestamp of incoming data	[802.15.4] 6.3.2	O	N
MLF3	Beacon management	[802.15.4] 5	M	Y
MLF3.1	Transmit beacons	[802.15.4] 5, 5.1.2.4	FD1: M FD2: O	FD1: Y FD2: N
MLF3.2	Receive beacons	[802.15.4] 5, 6.2.4	M	Y
MLF4	Channel access mechanism	[802.15.4] 5, 5.1.1	M	Y
MLF5	Guaranteed time slot (GTS) management	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF5.1	GTS management (allocation)	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF5.2	GTS management (request)	[802.15.4] 5, 6.2.6, 5.3.9, 5.1.7	O	N
MLF6	Frame validation	[802.15.4] 6.3.3, 5.2, 5.1.6.2	M	Y
MLF7	Acknowledged frame delivery	[802.15.4] 5, 6.3.3, 5.2.1.1.4, 5.1.6.4	M	Y
MLF8	Association and disassociation	[802.15.4] 5, 6.2.2, 6.2.3, 5.1.3	M	Y
MLF9	Security	[802.15.4] 7	M	Y
MLF9.1	Unsecured mode	[802.15.4] 7	M	Y
MLF9.2	Secured mode	[802.15.4] 7	O	Y
MLF9.2.1	Data encryption	[802.15.4] 7	O.4	Y
MLF 9.2.2	Frame integrity	[802.15.4] 7	O.4	Y
MLF10.1	ED	[802.15.4] 5.1.2.1, 5.1.2.1.1	FD1: M FD2: O	FD1: Y FD2: N
MLF10.2	Active scanning	[802.15.4] 5.1.2.1.2	FD1: M FD2: O	FD1: Y FD2: Y
MLF10.3	Passive scanning	[802.15.4] 5.1.2.1.2	M	Y

MLF10.4	Orphan scanning	[802.15.4] 5.1.2.1, 5.1.2.1.3	M	Y
MLF11	Control/define/determine/declare superframe structure	[802.15.4] 5.1.1.1	FD1: O	N
MLF12	Follow/use superframe structure	[802.15.4] 5.1.1.1	O	N
MLF13	Store one transaction	[802.15.4] 5.1.5	FD1: M	FD1: Y
MLF14	Ranging	[802.15.4] 5.1.8	RF4: O	N
MLF14.1	DPS	[802.15.4] 5.1.8.3, 6.2.15	O	N
MLF15(4g)	MPM for all coordinators when operating at more than 1% duty cycle	[802.15.4g] 5.1.13	M	Y
MLF15	TSCH Capability	[802.15.4e] Table 8a	O	N
MLF16	LL Capability	[802.15.4e] Table 8b	O	N
MLF17	DSME Capability	[802.15.4e] 6.2, Table 8c	O	N
MLF18	EBR capability	[802.15.4e] 5.3.12	O	Y
MLF18.1	EBR commands	[802.15.4e] 5.3.7	MLF18: O	Y
MLF18.1.1	EBR Enhanced Beacon request command	[802.15.4e] 5.3.7.2	FD1: M FD2: O	FD1: Y FD2: Y
MLF19	LE capability	[802.15.4e] 5.1.1.7, 5.1.11	O	O (#1)
MLF19.1	LE specific MAC sub-layer service specification	[802.15.4e] 6.4.3.7	MLF19: M	MLF19: Y
MLF19.2	Coordinated Sampled Listening (CSL) capability	[802.15.4e] 5.1.11.1	MLF19: O.1	MLF19: O.1
MLF19.3	Receiver Initiated Transmission (RIT) capability	[802.15.4e] 5.1.11.2	MLF19: O.1	MLF19: O.1
MLF19.4	LE superframe	[802.15.4e] 5.1.1.7.1, 5.1.1.7.2, 5.1.1.7.3	MLF19: O.1	N
MLF19.5	LE-multipurpose Wake-up frame	[802.15.4e] 5.2.2.8	MLF19.2: M	MLF19.2: Y
MLF19.6	LE, CSL Information Element	[802.15.4e] 5.2.4.7	MLF19.2: M	MLF19.2: Y
MLF19.7	LE RIT Information Element	[802.15.4e] 5.2.4.8	MLF19.3: O	MLF19.3: O
MLF19.8	LE-commands	[802.15.4e] 5.3.12	MLF19.3: M	MLF19.3: Y
MLF20	MAC Metrics PIB Attributes	[802.15.4e] 6.4.3.9	O	N
MLF21	FastA commands	[802.15.4e] 5.1.3.3	O	N
MLF23	Channel Hopping	[802.15.4e] Table 52f	O	N
MLF23.1	Hopping IEs	[802.15.4e] 5.2.4.16, 5.2.4.17	MLF18: M	N

O.1: Optional but at least one of the features described in FD1 and FD2 is required to be implemented

O.4: At least one of these features shall be supported.

#1: Implementation is optional.

The requirements for the MAC frames are described in **Table 5-8**.

Table 5-8: MAC frames

Item number	Item description	Reference section in standard	Status in standard (M: Mandatory, O: Option)		Support (Y: Yes, N: No, O: Option)
			Transmitter	Receiver	
MF1	Beacon	[802.15.4] 5.2.2.1	FD1: M	M	Y
MF2	Data	[802.15.4] 5.2.2.2	M	M	Y
MF3	Acknowledgment	[802.15.4] 5.2.2.3	M	M	Y
MF4	Command	[802.15.4] 5.2.2.4	M	M	Y
MF4.1	Association request	[802.15.4] 5.2.2.4, 5.3.1	M	FD1: M	Y
MF4.2	Association response	[802.15.4] 5.2.2.4, 5.3.2	FD1: M	M	Y
MF4.3	Disassociation notification	[802.15.4] 5.2.2.4, 5.3.3	M	M	Y
MF4.4	Data request	[802.15.4] 5.2.2.4, 5.3.4	M	FD1: M	Y
MF4.5	PAN identifier conflict notification	[802.15.4] 5.2.2.4, 5.3.5	M	FD1: M	Y
MF4.6	Orphaned device notification	[802.15.4] 5.2.2.4, 5.3.6	M	FD1: M	Y
MF4.7	Beacon request	[802.15.4] 5.2.2.4, 5.3.7	FD1: M	FD1: M	Y
MF4.8	Coordinator realignment	[802.15.4] 5.2.2.4, 5.3.8	FD1: M	M	Y
MF4.9	GTS request	[802.15.4] 5.2.2.4, 5.3.9	MLF5: O	MLF5: O	N
MF5	4-octet FCS	[802.15.4g] 5.2.1.9	FD8: M	FD8: M	O(#1)

#1: Implementation is optional.

5.5. Interface part

5.5.1. Overview

The interface part shall be composed of the transport, network, and adaptation layers. The data from the transport/network layer is converted to physical/data link layer data via the adaptation layer. On the other hand, the data from the physical/data link layer is converted to transport/network layer data via the adaptation layer. As transport layer protocol, UDP or TCP may be supported.

5.5.2. Requirements

(1) The interface part shall provide a network interface. The MAC address in the network interface shall be the EUI-64 address that is extracted from the IEEE 802.15.4 MAC part.

(2) The interface part shall know the address configuration used in the MAC part in advance.

(3) The interface part shall analyze the IPv6 header according to the address configuration used in the MAC part. The part must convert the destination address in the IPv6 header to the address to be transmitted by the MAC part.

(4) The interface part shall analyze the IPv6 header. When the destination address is a multicast address, the part shall instruct the MAC part to do broadcast transmission.

(5) The interface part shall use neighbor discovery based on IPv6 or 6LowPAN. The neighbor discovery is chosen not by node, but by system.

5.5.3. Adaptation layer

The adaptation layer in the interface part shall support 6LoWPAN [6LOWPAN] and IPHC on 6LoWPAN [6LPHC] with compression of the IPv6 header and, if needed, fragmentation support. The requirements for the adaptation layer using 6LoWPAN are given in **Table 5-9**.

Table 5-9: Adaptation layer for 6LoWPAN

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
6LP1.1	Addressing Mode (EUI-64)	[6LOWPAN] 3	Y
6LP1.2	Addressing Mode (short address)	[6LOWPAN] 3	N
6LP2	Frame Format	[6LOWPAN] 5	O (#1)
6LP3	Stateless Address Autoconfiguration	[6LOWPAN] 6	Y
6LP4	IPv6 Link Local Address	[6LOWPAN] 7	Y
6LP5	Unicast Address Mapping	[6LOWPAN] 8	Y (#2)
6LP6	Multicast Address Mapping	[6LOWPAN] 9	N
6LP7	Encoding of IPv6 Header Fields	[6LOWPAN] 10.1	N (#3)
6LP8	Encoding of UDP Header Fields	[6LOWPAN] 10.2	N (#3)
6LP9	Non-Compressed Fields	[6LOWPAN] 10.3	Y
6LP10	Frame Delivery in a Link-Layer Mesh	[6LOWPAN] 11	N

(#1) Header Type = LOWPAN_HC1 shall not be used. Header Type = LOWPAN_BC0 and [6LOWPAN] 5.2 are optional.

(#2) 16-bit addresses (short address) shall not be used.

(#3) For header compression, HC1 and HC2 in [6LOWPAN] shall not be used and IPHC [6LPHC] shall be used.

5.5.3.1. Fragmentation

The fragmentation specified in [6LOWPAN] shall be supported. The requirements for 6LoWPAN fragmentation to be implemented are described in **Table 5-10**. All nodes shall support fragmentation specified in [6LOWPAN].

Table 5-10: 6LoWPAN fragmentation

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
6LPF1	Fragmentation type and Header	[6LOWPAN] 5.3	Y

5.5.3.2. Header compression

The requirements for 6LoWPAN header compression to be implemented are described in **Table 5-11**. Basically, every node shall support header compression specified in [6LPHC]. However, the header compression using a context ID (including compression of stateful multicast addresses) shall not be supported. Moreover, the compression of the IPv6 extension header and UDP header by LOWPAN_NHC shall not be supported. A node that receives an IPv6 packet shall be able to receive IPv6 packets without header compression and IPv6 packets encoded without using the above-mentioned excluded functions among the header compression methods specified in [6LPHC]. The packets include IPv6 packets encoded by applying only a portion of the header compression specified in [6LPHC].

Table 5-11: 6LoWPAN header compression

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
6HC1.1	LOWPAN_IPHC (Base Format)	[6LPHC] 3.1.1	Y
6HC1.2	Context Identifier Extension	[6LPHC] 3.1.2	N
6HC2.1	Stateless Multicast Address Compression	[6LPHC] 3.2.3	Y
6HC2.2	Stateful Multicast Address Compression	[6LPHC] 3.2.4	N
6HC4	LOWPAN_NHC (IPv6 Extension Header Compression)	[6LPHC] 4.2	N
6HC5	LOWPAN_NHC (UDP Header Compression)	[6LPHC] 4.3	N

The context ID shall not be supported and a link local address based on the EUI-64 address is used as the IPv6 address as described below. The LOWPAN_IPHC encoding header **[**6LPHC**]** in an IPv6 unicast packet transmitted by a node compliant with this system is shown in **Figure 5-3**.

(bit)

0	1	2	3 4	5	6 7	8	9	10	11	12	13	14	15
0	1	1	TF *1	NH *2	HLIM *3	0	0	1	1	0	0	1	1

Figure 5-3: LOWPAN_IPHC encoding header (for unicast)

*1: TF = 0b11 (Traffic Class and Flow Label are elided.)

*2: NH = 0b0 (Full 8 bits for Next Header are carried in-line.)

*3: HLIM = 0b11 (The Hop Limit field is compressed and the hop limit is 255.)

5.5.3.3. Neighbor discovery

For neighbor discovery, RFC 4861 [ND] defined for IPv6 shall basically be used, but RFC 6775 optimized for 6LoWPAN may be used. The requirements for 6LoWPAN neighbor discovery to be implemented when RFC 6775 is used are described in **Table 5-12**. The specifications for routing used for realizing multihop functions are out of scope of this specification.

Table 5-12: 6LoWPAN neighbor discovery

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
6ND1	DHCPv6 Address Assignment for 6LBR, 6LR and Host	[6LPND] 3.2	O
6ND2	DHCPv6 Prefix Delegation for 6LBR	[6LPND] 3.2, 7.1	O
6ND3	DHCPv6 Prefix Delegation for 6LR and Host	[6LPND] 3.2, 7.1	O
6ND4	Static IPv6 address configuration on 6LBR	[6LPND] 5.4.1	O
6ND5	Static IPv6 address configuration on 6LR and Host	[6LPND] 5.4.1	O
6ND6	EUI-64 based IPv6 Address Generation	[6LPND] 5.4.1	Y
6ND7	802.15.4 16-bit short address	[6LPND] 1.3	N
6ND8	802.15.4 64-bit extended address	[6LPND] 1.3	Y
6ND9	Duplicate Address Detect	[6LPND] 4.4	O
6ND10	Duplicate Address messages (DAR and DAC)	[6LPND] 4.4	O
6ND11	Support Source Link-Layer Address Option (SLLAO)	[6LPND] 4.1, 5.3	Y
6ND12	Support Address Registration Option (ARO)	[6LPND] 5.5	Y
6ND13	Support Authoritative Border Router Option (ABRO)	[6LPND] 3.3, 3.4, 4.3, 6.3	O
6ND14	Support Prefix Information Option (PIO)	[6LPND] 3.3, 5.4	O
6ND15	Support 6LoWPAN Context Option (6CO)	[6LPND] 4.2	O
6ND16	Multihop Prefix and Context Distribution	[6LPND] 8.1	O
6ND17	Multihop DAD	[6LPND] 8.2	O
6ND18	Support Router Discovery	[6LPND]	Y
6ND19	Support RA based Address Configuration on 6LR and Host	[6LPND] 5.4.1	O
6ND20	Support Neighbor Cache Management	[6LPND] 3.5	Y
6ND21	Support Address Registration	[6LPND] 3.2	Y
6ND22	Support Address unregistration	[6LPND] 3.2	Y
6ND23	Support Neighbor Unreachable Detection	[6LPND] 5.5	Y
6ND24	Send Multicast NS	[6LPND] 6.5.5	O
6ND25	Send Unicast NS	[6LPND] 5.5	Y

5.5.4. Network layer

The network layer in the interface part shall implement the requirements in **Table 5-13** based on the IPv6 protocol defined in [IPv6]. Hop-by-Hop Options, Routing, Fragment, and Destination Options extension headers, and AH and

ESP extension headers related to IPSec may not be supported. Each extension header shall be transmitted according to the recommended order defined in [IPv6].

ICMPv6 [ICMPv6] described in **Table 5-14** shall be supported. In addition to the Echo Request Message (type 128) and Echo Reply Message (type 129), the following error messages shall also be supported: Destination Unreachable Message (type 1), Time Exceeded Message (type 3), and Parameter Problem Message (type 4). For the Packet Too Big Message (type 2), the network layer may not has the transmission function, but shall process the message properly when received.

Table 5-13: Network layer: IPv6

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
IP1	Header Format	[IPv6] 3	Y
IP1.1	Extension Headers	-	Y
IP1.2	Extension Header Order	[IPv6] 4.1	Y
IP1.3	Options	[IPv6] 4.2	Y
IP1.4	Hop-by-Hop Options Header	[IPv6] 4.3	O
IP1.5	Routing Header	[IPv6] 4.4	O
IP1.6	Fragment Header	[IPv6] 4.5	O
IP1.7	Destination Options Header	[IPv6] 4.6	O
IP1.8	No Next Header	[IPv6] 4.7	Y
IP1.9	AH Header	[IPv6-SAA]	O
IP1.10	ESP Header	[IPv6-MIB]	O
IP2	Deprecation of Type 0 Routing Headers	[IPv6-RH]	Y
IP3	Path MTU Discovery	[IPv6] 5	Y
IP4	Flow Labels	[IPv6] 6	Y
IP5	Traffic Classes	[IPv6] 7	Y

Table 5-14: Network layer: ICMPv6

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
ICMP1	Message Format	[ICMP6] 2.1	Y
ICMP2	Message Source Address Determination	[ICMP6] 2.2	Y
ICMP3	Message Checksum Calculation	[ICMP6] 2.3	Y
ICMP4	Message Processing Rules	[ICMP6] 2.4	Y
ICMP5	Destination Unreachable Message	[ICMP6] 3.1	Y
ICMP6	Packet Too Big Message	[ICMP6] 3.2	Y
ICMP7	Time Exceeded Message	[ICMP6] 3.3	Y
ICMP8	Parameter Problem Message	[ICMP6] 3.4	Y
ICMP9	Echo Request Message	[ICMP6] 4.1	Y
ICMP10	Echo Reply Message	[ICMP6] 4.2	Y

5.5.4.1. IP addressing

The items listed in **Table 5-15** based on IPv6 addressing specified by document [IP6ADDR] and IPv6 Stateless Address Autoconfiguration specified by document [SLAAC] shall be implemented. A network defined by this system always uses link local addresses based on EUI-64 addresses. According to the description in [6LOWPAN] and [SLAAC], well known link-local prefix FE80::0/64 is used as the prefix and an interface identifier is generated from the EUI-64 address. IPv6 link local addresses, global addresses, and unique local addresses based on short addresses specified in [802.15.4] are not used in this standard.

Table 5-15: Network layer: IP addressing

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
IPAD1	IPv6 Addressing	[IP6ADDR]	Y (#1)
IPAD1.1	Global Unicast Address	[IP6ADDR] 2.5.4	N
IPAD1.2	Link Local Unicast Address	[IP6ADDR] 2.5.6	Y (#2)
IPAD1.3	Unique Local Unicast Address	[ULA]	N
IPAD1.4	Anycast Address	[IP6ADDR] 2.6	N
IPAD1.5	Multicast Address	[IP6ADDR] 2.7	Y (#3)
IPAD1.6	Prefix Length		/64
IPAD2	Stateless Address Autoconfiguration	[SLAAC]	Y
IPAD2.1	Creation of Link Local Address	[SLAAC] 5.3	Y
IPAD2.2	Creation of Global Addresses	[SLAAC] 5.5	N

(#1) Some of the functions are not used.

(#2) MAC EUI-64 address based Link Local Addresses is used.

(#3) ff02::1 is used for transmission.

5.5.4.2. Neighbor discovery

For neighbor discovery, RFC 4861 [ND] defined for IPv6 shall be used. The requirements for IPv6 neighbor discovery to be implemented when [ND] is used are described in **Table 5-16**. A node compliant with the specification of this system shall support the following two functions defined in [ND]: Address Resolution and Duplicate Address Detection and shall support the following ICMPv6 messages defined in [ND]: Neighbor Solicitation Message (type = 135) and Neighbor Advertisement Message (type = 136).

Table 5-16: Network Layer: IPv6 neighbor discovery

Item number	Item description	Reference section in standard	Support (Y: Yes, N: No, O: Option)
ND1	Router and Prefix Discovery	[ND] 6	N
ND2	Address Resolution	[ND] 7.2	Y
ND3	Neighbor Unreachability Detection	[ND] 7.3	N
ND4	Duplicate Address Detection	[SLAAC] 5.4	O
ND5	Redirect Function	[ND] 8	N
ND6	Router Solicitation Message	[ND] 4.1	N
ND7	Router Advertisement Message	[ND] 4.2	N
ND8	Neighbor Solicitation Message	[ND] 4.3	Y(*1)
ND9	Neighbor Advertisement Message	[ND] 4.4	Y(*2)
ND10	Redirect Message	[ND] 4.5	N
ND11	Source/Target Link-layer Address Option	[ND] 4.6.1	Y
ND12	Prefix Information Option	[ND] 4.6.2	N
ND13	Redirected Header Option	[ND] 4.6.3	N
ND14	MTU Option	[ND] 4.6.4	N

*1: The Source Link-Layer Address Option contains an EUI-64 format address.

*2: The Target Link-Layer Address Option contains an EUI-64 format address.

5.5.4.3. Multicast

For ECHONET Lite payload multicast transmission, ff02::1 shall be set as the destination address according to the ECHONET Lite specification [EL].

5.5.5. Transport layer

UDP [UDP] shall be implemented and TCP [TCP] may be implemented. UDP shall always be available also when TCP is implemented, however. The destination port number in UDP and TCP frames and operation procedure for TCP shall follow the specification in [EL].

5.5.6. Application layer

As the application layer, ECHONET Lite [EL] shall be used. A node compliant with the specification defined for this system shall support all requirements specified in [EL].

5.6. Security configuration

5.6.1. Overview

In this specification, PANA shall be used for network connection authentication and the MAC layer shall be used for communication protection (encryption) for communication security. EAP-PSK shall be used as the EAP method used by PANA and AES-128-CCM* described in [802.15.4] shall be used as the algorithm for authenticated encryption in the MAC layer.

5.6.2. Authentication

In this specification, a coordinator shall be a PAA and a host shall be a PaC.

5.6.2.1. PANA

- Internet Protocol Version 6 (IPv6) and UDP shall be used.
- The PaC shall know the IP address of the PAA before starting a PANA session.
- The destination port number used by the PAA/PaC shall be 716 (PANA default value).
- Only the start of a PANA session by the PaC shall be supported (the start of a PANA session by the PAA is not supported).
- As the key derivation algorithm (PRF-Algorithm), PRF_HMAC_SHA2_256 (AVP Value = 5) shall be used.
- As the message authentication algorithm (Integrity-Algorithm), AUTH_HMAC_SHA2_256_128 (AVP Value=12) shall be used.
- An EAP-Response message shall always be piggybacked on the PANA-Auth-Answer message.
- The length of the Nonce value shall be 16 octets.
- The lifetime value can be specified with an unsigned 4-octet value in seconds. The value shall not be less than 60 seconds.

5.6.2.2. EAP

- As the EAP authentication method, EAP-PSK based on a shared key shall be used.
- The length of an EAP-PSK authentication key shall be 16 octets.
- The length of the Master Session Key (MSK) and Extended Master Session Key (EMSK) passed from the EAP layer to the PANA protocol layer shall be 64 octets.
- The server authenticator, EAP ID_S, shall be a NAI specified in [NAI].

In this specification, the length of the NAI shall not exceed 63 octets.[1]

- The client authenticator, EAP ID_P, shall be a NAI specified in [NAI].

In this specification, the length of the NAI shall not exceed 63 octets.

- The retransmission of messages in the EAP layer shall be invalid.

5.6.3. Key update

The lifetime of a key used for protecting PANA itself (PANA_AUTH_KEY) and a key used in the MAC layer that is shared between the coordinator and host as the result of successful connection authentication by PANA shall be the same as the PANA session lifetime. A newly derived key shall be used after PANA session renewal (PANA session renewal by the Re-Authentication phase or new PANA session establishment by the Authentication and Authorization phase). If a PANA session is terminated before the PANA session lifetime expiration, any keys derived in this session

[1] According to RFC 4282 2.2, the value must not exceed the RADIUS limit.

shall be revoked.

5.6.3.1. PANA key derivation function

The PANA_AUTH_KEY, which is required for generating the AUTH AVP securing the integrity of a PANA message, shall follow [PANA], and PRF-HMAC-SHA-256 shall be used as the prf() function.

As the PANA_AUTH_HASH() function used for deriving the AUTH AVP value using the generated PANA_AUTH_KEY, which is a hash function negotiated by the Integrity-Algorithm AVP, AUTH_HMAC_SHA_256_128 shall be used in this specification.

5.6.3.2. EAP-PSK key derivation function

The derivation of the TEK (16 octets), MSK (64 octets), and EMSK (64 octets) generated by EAP-PSK negotiation shall follow [EAP-PSK].

5.6.3.3. MAC layer key derivation function

Security keys used in the MAC layer shall be derived using the EMSK derived as the result of EAP-PSK negotiation. First, the SMMK, master key for generating MAC layer keys, is generated using the USRK derivation function [USRK] and the SMK-HH, MAC layer key between devices is derived using the SMMK.

SMMK = KDF(EMSK, “Wi-SUN JP SH-HAN" | "¥0" | optional data | length)
- optional data = NULL(0x00)
- length = 64

SMK-HH = KDF(SMMK, “Wi-SUN JP SH-HAN" | "¥0" | optional data | length)
- optional data = EAP ID_P | EAP ID_S | IEEE802.15.4 Key Index
- length = 16

As the KDF, the same key derivation function as for PANA, that is, prf+() using PRF_HMAC_SHA2_256 is used. The value of length in optional data required for generating the SMMK and SMK-HH is an unsigned 8-bit integer. The IEEE 802.15.4 Key Index is the lower 8-bit value of the SMMK KEY ID (32-bit MSK Identifier in the Key-Id AVP given by the PAA in the PANA session). For this reason, the PAA shall not assign consecutively MSK Identifiers that have the same lower 8-bit value to the same PaC.

The MAC layer key (SMK-HH) is derived from the master key (EMSK) shared only between devices as successful authentication by PANA. For this reason, there is a one-to-one connection between the devices.

5.6.4. Encryption and manipulation detection

Encryption of the MAC data frame based on [802.15.4] shall be done using the MAC layer key (SMK-HH key) obtained by the establishment of a PANA session.

If a new MAC layer key is generated after the establishment of a new PANA session or the update of the PANA session, the transmission MAC frame shall be encrypted using the newest MAC layer key.

The Frame Counter value in the MAC frame shall be reset each time a new MAC layer key is used. The host shall update the PANA session to a new one before the Frame Counter value in the incoming/outgoing MAC frame overflows even before the expiration of the lifetime of the existing PANA session.

For encryption, to implement both confidentiality and authenticity, ENC-MIC-32 (security level 5) shall be used. If MIC verification of an incoming MAC frame fails, the frame shall be discarded.

Key Identifier Mode shall be 0x01. In the Key Identifier field, Key Source shall not be set and only 1-octet Key Index

shall be set.

Exception to the application of encryption

Encryption shall not be applied to PANA messages (UDP destination port 716) and IPv6 Neighbor Solicitation (NS) (ICMPv6 Type 135 Code 0)/Neighbor Advertisement (NA) (ICMPv6 Type 136 code 0) messages and no MAC Auxiliary Security header shall be added.

5.6.5. Protection from replay attacks

Target messages for MAC frame encryption shall be protected from replay attacks by Frame Counter processing for the MAC Auxiliary Security header in [802.15.4]. That is, if the Frame Counter value in a new incoming MAC frame is smaller than that in the received MAC frame, the new MAC frame shall be discarded.

5.7. Frame formats

The frame formatting procedure in each layer for UDP communication is shown in **Figure 5-4**, **Figure 5-5**, **Figure 5-6**, and **Figure 5-7**.

Variable
ECHONET Lite Payload

Figure 5-4: ECHONET Lite Payload

40 byte	0 − n byte	8 byte	Variable
IPv6 Header	Ext Header	UDP Header	ECHONET Lite Payload

Figure 5-5: IPv6 frame configured in the interface part

2 - 3 byte	Depends on LOWPAN_IPHC	0 – n byte	Variable
LOWPAN_IPHC Encoded	In-line IP fields	In-line Next Header Fields	ECHONET Lite Payload

Figure 5-6: 6LowPAN frame configured in the interface part

Variable	2 - 3 byte	Depends on LOWPAN_IPHC	0 – n byte	Variable	2 byte
IEEE 802.15.4 header	LOWPAN_IPHC Encoded	In-line IP fields	In-line Next Header Fields	ECHONET Lite Payload	FCS

Figure 5-7: IEEE 802.15.4 frame configured in the MAC part

5.8. Recommended specification for configuring a single-hop network

5.8.1. Overview

This section describes the recommended specification for constructing a single-hop network using ECHONET Lite on IPv6 in system A. Other specifications are not excluded as far as system A specification is conformed.

Nodes based on the specification in this section construct a single-hop network where a coordinator is centered. And, with assuming a gateway connection provided by the application layer as the connection measure to external networks, a closed IP network is assumed inside this system. On those assumptions, the indoor network construction using ECHONET Lite provides expandability as well as feasibility.

5.8.2. Construction of a new network

Once turned on, a coordinator constructs a new network compliant with this system specification. The network construction is conducted by successive steps of (1) data link layer configuration, (2) network layer configuration, and (3) security configuration. An overview of the network construction procedure is shown in **Figure 5-8**.

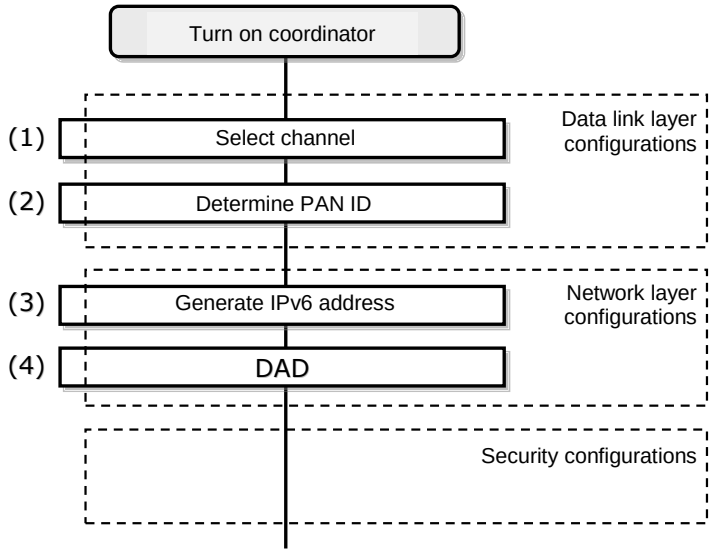


Figure 5-8: Overview of network construction procedure

5.8.2.1. Data link layer configurations

Once turned on, a coordinator constructs an IEEE 802.15.4 PAN. A detailed procedure for PAN construction is as follows.

The coordinator first selects a channel to use. The channel selection is conducted via ED scanning or active scanning. In the selection, a channel with less interference to the other systems is more preferable. (Step 1)

Next, the coordinator selects a PAN ID that is not occupied by any PAN on the channel selected in Step 1, and defines it as the PAN ID to be used in the network the coordinator manages. For this system, the following procedure is not specified: How the coordinator selects a PAN ID that is not occupied by any PAN on the channel selected in Step 1 as the PAN ID of the local network. (Step 2)

After the previous steps, the coordinator completes the PAN construction using the determined radio channel and PAN ID.

5.8.2.2. Network layer configurations

After data link layer configurations are completed, the coordinator conducts initial configurations for the network layer (IPv6).

First, the coordinator generates its own IPv6 address. The prefix is FE80::0/64, and an interface identifier is generated based on coordinator's MAC address (EUI-64) according to definitions in [6LOWPAN] and [SLAAC]. (Step

3)

The coordinator may provide the global address or an unique local address to the IEEE 802.15.4/4e/4g interface that defines the IP address generated in Step 3, which is out of scope of this system specification. For the coordinator, there may also be an interface other than the IEEE 802.15.4/4e/4g interface used in this network, which is also out of scope of this system specification.

In general cases for IPv6 address configurations, Duplicate Address Detection (DAD) is conducted in this step to check that the IP address is not used by the other nodes in the network. However, nodes compliant with this system specification always generate an IPv6 address from an EUI-64 address and there is basically no confliction of IP addresses in this system network. Therefore, DAD may be omitted. (Step 4)

5.8.2.3. Security configurations

The coordinator conducts security configurations following data link layer and network layer configurations. Security technologies employed in the constructed network should be selected according to the application requirements. This system specification does not describe a specific procedure for security configurations conducted by the coordinator.

Note that security configurations may be conducted during (data link layer configurations and) network layer configurations.

5.8.3. Joining in a network

Once turned on, a new host tries to join the existing network compliant with this system. The joining procedure by the host includes (1) data link layer configuration, (2) network layer configuration, and (3) security configuration just in a same manner as the network construction by a coordinator. An overview of the procedure for joining the existing network by a new host is shown in **Figure 5-9**.

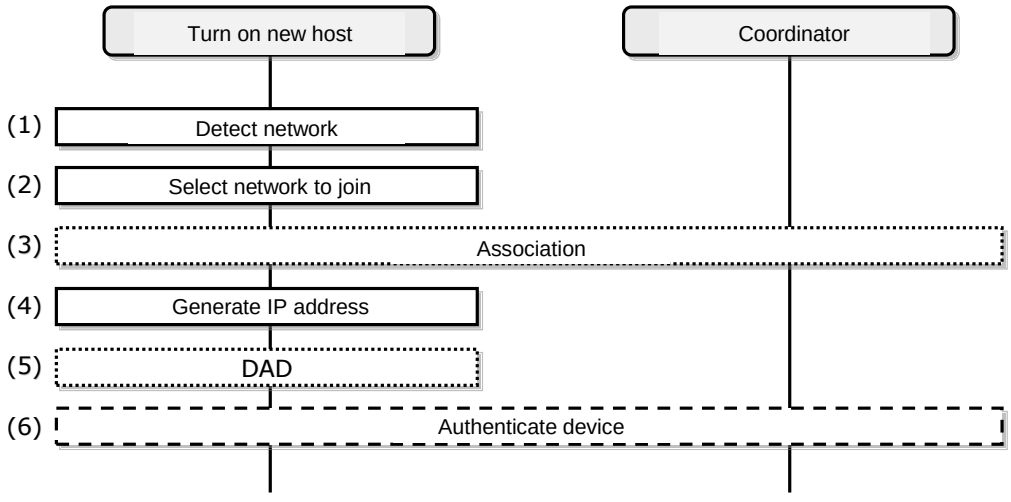


Figure 5-9: Overview of network joining procedure

5.8.3.1. Data link layer configurations

Once turned on, first, a new host detects an existing IEEE 802.15.4 PAN around it. The PAN detection procedure is as follows: The new host transmits a beacon request command message specified in [802.15.4] to all available radio channels specified in [802.15.4] and [T108]. A coordinator that receives the message transmits a beacon frame as a

response. The new host receives the beacon. Moreover, the new host can recognize the radio channel and PAN ID employed by the coordinator, as a result of this procedure. (Step 1)

If only one PAN is detected in Step 1, the host proceeds to the next step for that PAN. If multiple PANs are detected, the host selects one of them and proceeds to the next step. Which PAN the host selects depends on the implementation. (Step 2)

If the new host fails to join the selected PAN in the following network joining procedure, the host is recommended to retry the joining procedure from Step 1 or 2. In the retry procedure, the host should select a network other than that the host fails to join.

At this point, the new host may conduct association specified in [802.15.4]. Since the host is to recognize the coordinator in an upper layer, however, association in the data link layer may be omitted. (Step 3)

5.8.3.2. Network layer configurations

After the new host has joined an IEEE 802.15.4 PAN, it generates its own IPv6 address. The prefix is FE80::0/64, and an interface identifier is generated based on host's MAC address (EUI-64) according to definitions in [6LOWPAN] and [SLAAC]. (Step 4)

In general cases for IPv6 address configurations, Duplicate Address Detection (DAD) is conducted in this step to check that the IP address is not used by the other nodes in the network. However nodes compliant with this system specification always generate an IPv6 address from an EUI-64 address and there is basically no confliction of IP addresses in this system network. Therefore, DAD may be omitted. (Step 5)

At this point, the new host is authenticated as a device by the coordinator. The device authentication procedure is out of scope of this system specification. The new host recognizes the authenticating node as the coordinator and stores coordinator's address information. (Step 6)

5.8.3.3. Security configurations

After data link layer and network layer configurations are completed, the new host conducts security configurations with the coordinator. Security technologies employed in the constructed network should be selected according to the application requirements. This system specification does not describe a specific procedure for security configurations conducted by the coordinator.

5.8.4. Specifications for the device/physical layer/MAC layer to implement the recommended specification

Minimum required specifications in terms of IEEE 802.15.4/4e/4g to realize the specification in this section are shown in **Table 5-17**, **Table 5-18**, and **Table 5-19**. Under "Operation" in these tables, "Y" means a function used for this specification and "N" means a function not used for this specification. "O" means a function that may or may not be used according to the condition in the note. When the specification in this section is used, the non-beacon mode is used for the MAC layer.

Table 5-17: Device/physical layer specifications to implement the recommended specification

Item number *1	Operation: Support	Item number *2	Operation: Support	Item number *3	Operation: Support	Item number *3	Operation: Support
FD1	O.1	PLF1	Y	RF12	—	RF13.4	Supporting 100kbit/s or 50kbit/s, or the both
FD2	O.1	PLF2	Y	RF12.1	Y	RF13.5	N
FD3	Y	PLF3	Y	RF12.2	N	RF14	—
FD4	N	PLF4	Y	RF12.3	N	RF14.1	N
FD5	N	PLF4.1	Y	RF12.4	N	RF14.2	N
FD5	N	PLF4.1	Y	RF12.4	N	RF14.2	N
FD8	Y	PLF4.2	N	RF12.5	N	RF14.3	Y
		PLF4.3	N	RF12.6	Y	RF14.4	N
		PLP1	Supporting up to 255 octets	RF13	—		

*1: Corresponding to item number in **Table 5-6** Functional device types

*2: Corresponding to item number in **Table 5-1** PLF/PLP capabilities

*3: Corresponding to item number in **Table 5-2** RF capabilities

Table 5-18: MAC layer specifications to implement the recommended specification

Item number *1	Operation: Support	Item number *1	Operation: Support	Item number *1	Operation: Support	Item number *2	Operation: Support
MLF1	Y	MLF7	Y	MLF15	N	MF1	Y
MLF1.1	O*3*5	MLF8	O*6	MLF16	N	MF2	Y
MLF2	Y	MLF9	Y	MLF17	N	MF3	Y
MLF2.1	N	MLF9.1	Y	MLF18	Y	MF4	Y
MLF2.2	O*4	MLF9.2	Y	MLF18.1	Y	MF4.1	O*6
MLF2.3	N	MLF9.2.1	Y	MLF18.1.1	Y	MF4.2	O*6
MLF3	Y	MLF9.2.2	Y	MLF19	N*8	MF4.3	O*6
MLF3.1	Y*5	MLF10.1	Y*5	MLF19.1	N*8	MF4.4	O*3
MLF3.2	Y	MLF10.2	Y	MLF19.2	N*8	MF4.5	N
MLF4	Y	MLF10.3	N	MLF19.3	N	MF4.6	O*3
MLF5	N	MLF10.4	O*3	MLF19.4	N	MF4.7	Y*9
MLF5.1	N	MLF11	N	MLF19.5	N*8	MF4.8	O*3
MLF5.2	N	MLF12	N	MLF19.6	N*8	MF4.9	N
MLF6	Y	MLF13	O*3	MLF19.7	N	MF5	Y*10
		MLF15(4g)	O*7	MLF19.8	N		
				MLF20	N		
				MLF21	N		
				MLF23	N		
				MLF23.1	N		

*1: Corresponding to item number in **Table 5-7** MAC sub-layer functions

*2: Corresponding to item number in **Table 5-8** MAC frames

*3: May not be used for a network constructed only with devices with regular power supply.

*4: Can be used as necessary.

*5: Not used for a child device.

*6: May not be used when done in an upper layer.

*7: Used when 50kbit/s and 100kbit/s modes coexist.

*8: Not used since single-hop communications are assumed.

*9: Can also be used for a child device (clarifies an FD2 specification not included in the reference standard).

*10: Use 16-bit FCS when the PSDU size does not exceed 255 octets.

Table 5-19: Physical layer specifications to implement the recommended specification

Parameter	Specification for implementation	Remarks
Modulation scheme	GFSK	
Transmission rate	100kbit/s or 50kbit/s	
Transmission power	20mW	
Frequency channel	Channels of Nos. 33 to 60 specified in ARIB with bundling of an odd channel and the next even channel, or channels of Nos. 33 to 61 specified in ARIB	Channels of Nos. 33 to 38 are also used by systems with a transmission power of 250mW.
Occupied bandwidth	400kHz (with 2 channel bundling) or 200kHz	
Transmission preamble length	At least 15 bytes	

5.9. Recommended specification for single-hop smart meter- HEMS communication

5.9.1. Overview

This section describes the recommended specification for constructing a single-hop smart meter-HEMS network using ECHONET Lite on IPv6 in system A.

Nodes based on the specification in this section construct a single-hop network with a one-to-one connection between a smart meter as a coordinator and a HEMS.

5.9.2. Physical layer

Minimum required specification in terms of IEEE 802.15.4/4e/4g to realize the specification in this section is shown in **Table 5-20**. Under "Operation" in this table, "Y" means a function used for this specification and "N" means a function not used for this specification. When the specification in this section is used, the non-beacon mode is used for the MAC layer.

Table 5-20: Physical layer specification to implement the recommended specification

Item number *1	Operation: Support	Item number *2	Operation: Support	Item number *3	Operation: Support	Item number *3	Operation: Support
FD1	O.1	PLF1	Y	RF12	—	RF13.4	
FD2	O.1	PLF2	Y	RF12.1	Y	RF13.5	
FD3	Y	PLF3	Y	RF12.2	N	RF14	
FD4	N	PLF4	Y	RF12.3	N	RF14.1	
FD5	N	PLF4.1	Y	RF12.4	N	RF14.2	
FD8	Y	PLF4.2	N	RF12.5	N	RF14.3	
		PLF4.3	N	RF12.6	Y	RF14.4	
		PLP1	Supporting up to 255 octets	RF13	—		

*1: Corresponding to item number in **Table 5-3** Functional device types

*2: Corresponding to item number in **Table 5-1** PLF/PLP capabilities

*3: Corresponding to item number in **Table 5-2** RF capabilities

Table 5-21 lists radio interface specifications.

Table 5-21: Radio interface specifications

Parameter	Specification for implementation	Remarks
Modulation scheme	GFSK	
Transmission rate	100kbit/s	
Transmission power	20mW	
Frequency channel	Channels of Nos. 33 to 60 specified in ARIB with bundling of an odd channel and the next even channel, or channels of Nos. 33 to 61 specified in ARIB	Channels of Nos. 33 to 38 are also used by systems with a transmission power of 250mW.
Occupied bandwidth	400kHz (with 2 channel bundling)	
Receiver sensitivity	-88dBm or less @PER<10%, 250 octets (The specified measurement point of the receiver sensitivity is the end of the antenna connector.)	
Transmission preamble length	At least 15 bytes	1200us to 4000us
Reception preamble length	15 bytes	1200us
Antenna gain	3dBi or less	
Antenna diversity	2-antenna selection diversion is recommended.	

5.9.3. Data link (MAC) layer

5.9.3.1. Specifications in terms of IEEE 802.15.4/4e/4g

Minimum required specifications in terms of IEEE 802.15.4/4e/4g to realize the specification in this section are shown in **Table 5-22**. Under "Operation" in this table, "Y" means a function used for this specification and "N" means a function not used for this specification. When the specification in this section is used, the non-beacon mode is used for the MAC layer.

Table 5-22: MAC layer specifications to implement the recommended specification

Item number *1	Operation: Support	Item number *1	Operation: Support	Item number *1	Operation: Support	Item number *2	Operation: Support
MLF1	Y	MLF7	Y	MLF15	N	MF1	Y
MLF1.1	N	MLF8	N	MLF16	N	MF2	Y
MLF2	Y	MLF9	Y	MLF17	N	MF3	Y
MLF2.1	N	MLF9.1	Y	MLF18	Y	MF4	Y
MLF2.2	N	MLF9.2	Y	MLF18.1	Y	MF4.1	N
MLF2.3	N	MLF9.2.1	Y	MLF18.1.1	Y	MF4.2	N
MLF3	Y	MLF9.2.2	Y	MLF19	N	MF4.3	N
MLF3.1	Y*5	MLF10.1	Y*5	MLF19.1	N	MF4.4	N
MLF3.2	Y	MLF10.2	Y	MLF19.2	N	MF4.5	N
MLF4	Y	MLF10.3	N	MLF19.3	N	MF4.6	N
MLF5	N	MLF10.4	N	MLF19.4	N	MF4.7	Y*9
MLF5.1	N	MLF11	N	MLF19.5	N	MF4.8	N
MLF5.2	N	MLF12	N	MLF19.6	N	MF4.9	N
MLF6	Y	MLF13	N	MLF19.7	N	MF5	Y*10
		MLF15(4g)	N	MLF19.8	N		
				MLF20	N		
				MLF21	N		
				MLF23	N		
				MLF23.1	N		

*1: Corresponding to item number in **Table 5-4** MAC sub-layer functions

*2: Corresponding to item number in **Table 5-5** MAC frames

*5: Not used for a child device.

*9: Can also be used for a child device (clarifies an FD2 specification not included in the reference standard).

*10: Use 16-bit FCS when the PSDU size does not exceed 255 octets.

5.9.3.2. MAC frame formats

The MAC frame formats for this specification are described below based on [802.15.4] 5.2 MAC frame formats.

5.9.3.2.1. Data frame format

The data frame format used in this specification is shown in **Figure 5-10**. (This section clarifies the usage in this specification, based on [802.15.4e] 5.2.2.2 Data frame format.)

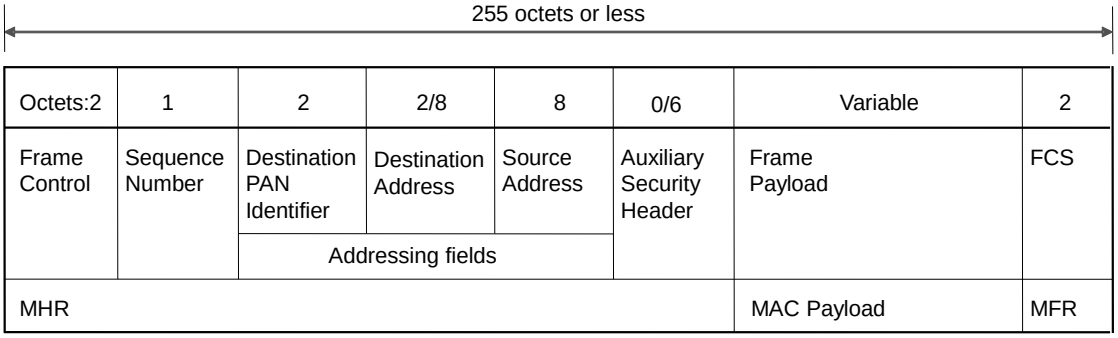


Figure 5-10: Data frame format

(1) Frame Control field

The fields in the Frame Control field are shown in **Table 5-23**.

Table 5-23: Frame Control (data frame)

bit	Field	Remarks
2-0	Frame Type	Set "001", which means a data frame.
3	Security Enable	Set "0" when security is disabled or "1" when security is enabled.
4	Frame Pending	Set "0" since this field is not used.
5	AR (Ack Request)	Set "0" when ACK is not requested (broadcast) or "1" when ACK is requested (unicast).
6	PAN ID Compression	Set "0" according to [802.15.4e] Table 2a.
7	Reserved	Set "0" basically, but assume don't care.
8	Sequence Number Suppression	Set "0" since the Sequence Number field is used.
9	IE List Present	Set "0" since IEs are not used.
11-10	Destination Addressing Mode	Set "11" for a unicast address since a 64-bit extended address is used. Set "10" for a broadcast address since a 16-bit short address is used.
13-12	Frame Version	Set "10" since extended format ACK is used. *1*2
15-14	Source Addressing Mode	Set "11" since a 64-bit extended address is used.

*1: This field is always set to 0b10 to indicate incompatibility with 802.15.4-2003/2006, assuming a response with the enhanced acknowledgment frame.

*2: The following specifications are assumed:

a) Devices compliant with this specification shall be capable of receiving a beacon, data, ACK, and command frames in which the Frame Version field is set to 10b.

b) Devices compliant with this specification may be capable of receiving a beacon, data, ACK, and command frames in which the Frame Version field is set to 00b or 01b.

c) Devices compliant with this specification shall set the Frame Version field to 10b when it generates a beacon, data, ACK, and command frames.

(2) Sequence Number field

See [802.15.4] 5.2.1.2 Sequence Number field.

(3) Addressing field

Source Address is a 64-bit MAC address. Destination Address is a 64-bit MAC address or 16-bit broadcast address (0xffff). These address fields are transmitted from the least significant octet and each octet is transmitted from the least significant bit (LSBit).

Source PAN Identifier is not included in the Addressing field. PAN Identifier is transmitted from LSBit, treated as a 16-bit numerical value.

(4) Auxiliary Security Header field

The fields in the Auxiliary Security Header field used for encrypting the frame are shown in **Table 5-24**.

Table 5-24: Auxiliary Security field

octet	bit	Field		Remarks
1	b2-b0	Security Control	Security Level	Set "101" since ENC-MIC-32 is used.
	b4-b3		Key Identifier Mode	Set "01" since a 1-octet key ID is used.
	b7-b5		Reserved	-
4	-	Frame Counter		
1	-	Key Identifier		

5.9.3.2.2. ACK frame format

The ACK frame format used in this specification is shown in **Figure 5-11**. (This section clarifies the usage in this specification, based on [802.15.4e] 5.2.2.3 Acknowledgment frame format.)

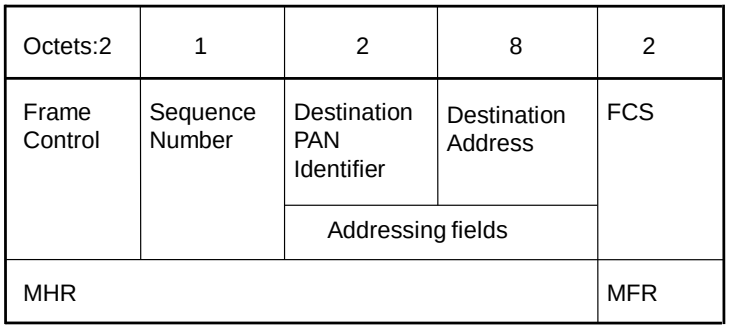


Figure 5-11: ACK frame format

(1) Frame Control field

The fields in the Frame Control field are shown in **Table 5-25**.

Table 5-25: Frame Control (ACK frame)

bit	Field	Remarks
2-0	Frame Type	Set "010", which means an ACK frame.
3	Security Enable	Set "0" since security is disabled.
4	Frame Pending	Set "0" since this field is not used.
5	AR(Ack Request)	Set "0".
6	PAN ID Compression	Set "0" according to [802.15.4e] Table 2a.
7	Reserved	Set "0".
8	Sequence Number Suppression	Set "0" since the Sequence Number field is used.
9	IE List Present	Set "0" since IEs are not used.
11-10	Destination Addressing Mode	Set "11" since a 64-bit extended address is used.
13-12	Frame Version	Set "10" since the extended format is used.
15-14	Source Addressing Mode	Set "00" since Source Address is not used.

(2) Sequence Number field

See [802.15.4] 5.2.1.2 Sequence Number field. In the ACK frame, this field is used to set the value in the target received data frame to respond.

(3) Addressing field

In Destination Address, set the Source Address value in the received frame to respond. See the description of "Addressing field" in Section 5.9.3.2.1 Data frame format in this specification.

5.9.3.2.3. Enhanced beacon frame format

The enhanced beacon frame format used in this specification is shown in **Figure 5-12**. (This section clarifies the usage in this specification, based on [802.15.4e] 5.2.2.1 Beacon frame format.)

<table>
<tr><td>Octets:2</td><td>1</td><td>2</td><td>8</td><td>8</td><td>Variable</td><td>2</td></tr>
<tr><td rowspan="2">Frame Control</td><td rowspan="2">Sequence Number</td><td>Destination PAN Identifier</td><td>Destination Address</td><td>Source Address</td><td rowspan="2">Payload IE</td><td rowspan="2">FCS</td></tr>
<tr><td colspan="3">Addressing fields</td></tr>
<tr><td colspan="5">MHR</td><td>MAC Payload</td><td>MFR</td></tr>
</table>

Figure 5-12: Enhanced beacon frame format

(1) Frame Control field

The fields in the Frame Control field are shown in **Table 5-26**.

Table 5-26: Frame Control (enhanced beacon frame)

bit	Field	Remarks
2-0	Frame Type	Set "000", which means a beacon frame.
3	Security Enable	Set "0" since security is disabled.
4	Frame Pending	Set "0" since this field is not used.
5	AR(Ack Request)	Set "1" since ACK is requested (unicast).
6	PAN ID Compression	Set "0" according to [802.15.4e] Table 2a.
7	Reserved	Set "0" basically, but assume don't care.
8	Sequence Number Suppression	Set "0" since the Sequence Number field is used.
9	IE List Present	Set "1" when IEs are used, or "0" when IEs are not used.
11-10	Destination Addressing Mode	Set "11" since a 64-bit extended address is used.
13-12	Frame Version	Set "10" since the extended format is used.
15-14	Source Addressing Mode	Set "11" since a 64-bit extended address is used.

(2) Sequence Number field

According to [802.15.4e] 5.2.2.1.1 Beacon frame MHR fields, set the sequence number (macEBSN) value held by the device.

(3) Addressing field

In Destination Address, set the Source Address value in the enhanced beacon request. See "Addressing field" in Section 5.9.3.2.1 Data frame in this specification.

In Destination PAN Identifier, set Source PAN Identifier of the device transmitting this frame.

(4) Payload IE field

Set the IEs field value set in the enhanced beacon request.

5.9.3.2.4. Enhanced beacon request command frame format

The enhanced beacon request command frame format used in this specification is shown in **Figure 5-13**. (This section clarifies the usage in this specification, based on [802.15.4e] 5.3.7.2 Enhanced beacon request.)

<table>
<tr><td>Octets:2</td><td>1</td><td>2</td><td>2</td><td>8</td><td>Variable</td><td>1</td><td>2</td></tr>
<tr><td rowspan="2">Frame Control</td><td rowspan="2">Sequence Number</td><td>Destination PAN Identifier</td><td>Destination Address</td><td>Source Address</td><td rowspan="2">Payload IE</td><td rowspan="2">Command Frame Identifier</td><td rowspan="2">FCS</td></tr>
<tr><td colspan="3">Addressing fields</td></tr>
<tr><td colspan="5">MHR</td><td colspan="2">MAC Payload</td><td>MFR</td></tr>
</table>

Figure 5-13: Enhanced beacon request command frame format

(1) Frame Control field

The fields in the Frame Control field are shown in **Table 5-27**.

Table 5-27: Frame Control (enhanced beacon request command frame)

bit	Field	Remarks
2-0	Frame Type	Set "011", which means a MAC command frame.
3	Security Enable	Set "0" since security is disabled.
4	Frame Pending	Set "0" since this field is not used.
5	AR(Ack Request)	Set "0" since ACK is not requested (broadcast).
6	PAN ID Compression	Set "0" according to [802.15.4e] Table 2a.
7	Reserved	Set "0".
8	Sequence Number Suppression	Set "0" since the Sequence Number field is used.
9	IE List Present	Set "1" when IEs are used, or "0" when IEs are not used.
11-10	Destination Addressing Mode	Set "10" since a 16-bit extended address is used.
13-12	Frame Version	Set "10" since the extended format is used.
15-14	Source Addressing Mode	Set "11" since a 64-bit extended address is used.

(2) Sequence Number field

See [802.15.4] 5.2.1.2 Sequence Number field.

(3) Addressing field

See "Addressing field" in Section 5.9.3.2.1 Data frame format.

(4) Payload IE field

See 5.9.6.1.1 Data link layer configuration in this specification.

(5) Command Frame Identifier field

According to [802.15.4e] Table 5, set "0x07".

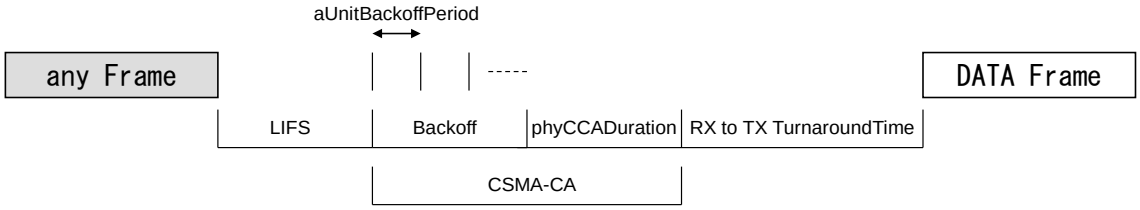
5.9.3.3. Main MAC functions

This section describes main MAC functions in this specification.

5.9.3.3.1. Transmission timing specification

(1) Data frame transmission timing specification

The specification of the transmission timing of a data frame is shown in **Figure 5-14**. (The figure clarifies the timing specification in this specification, based on the description in [802.15.4] 5.1.1.4 CSMA-CA algorithm, [802.15.4g] Table 51.)



Parameter *1	Formula	Value [μsec] (nominal) *2
LIFS	aTurnaroundTime	1000
aUnitBackoffPeriod	phyCCADuration＋aTurnaroundTime	1130
phyCCADuration	－	130
RX to TX TurnaroundTime	－	300 or more, 1000 or less

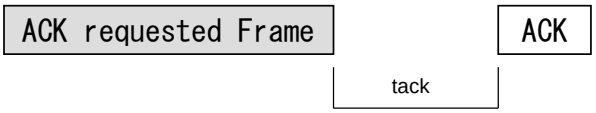
*1: See Section 5.9.3.3.5.

*2: For the error range of each value, see [802.15.4], [802.15.4e], and [802.15.4g].

Figure 5-14: Data frame transmission timing specification

(2) ACK frame transmission timing specification

The specification of the transmission timing of an ACK frame is shown in **Figure 5-15**. (The figure clarifies the timing specification in this specification by specifying the lower tack limit based on [802.15.4] 5.1.1.3 Interframe spacing (IFS).)



Parameter *1	Formula	Value [μsec]
tack	RX to TX TurnaroundTime	300 or more, 1000 or less *2

*1: See Section 5.9.3.3.5.

*2: TX to RX TurnaroundTime shall be less than 300μs.

Figure 5-15: ACK frame transmission timing specification

5.9.3.3.2. CSMA-CA

The CSMA-CA algorithm including retry is shown in **Figure 5-16**. (The figure clarifies the CSMA-CA algorithm including retry in this specification, based on [IEEE 802.15.4e] 5.1.1.4 CSMA-CA algorithm.)

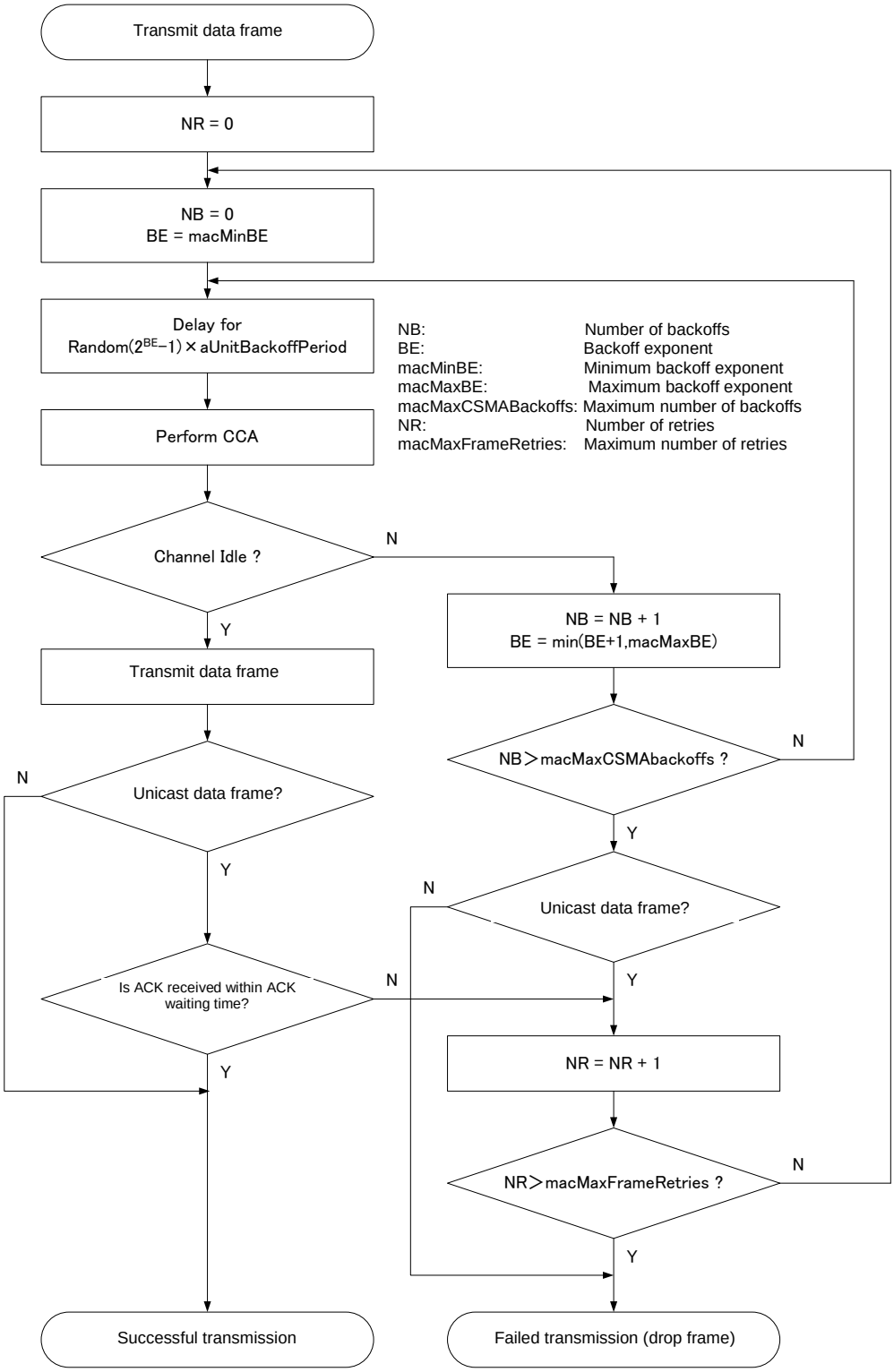
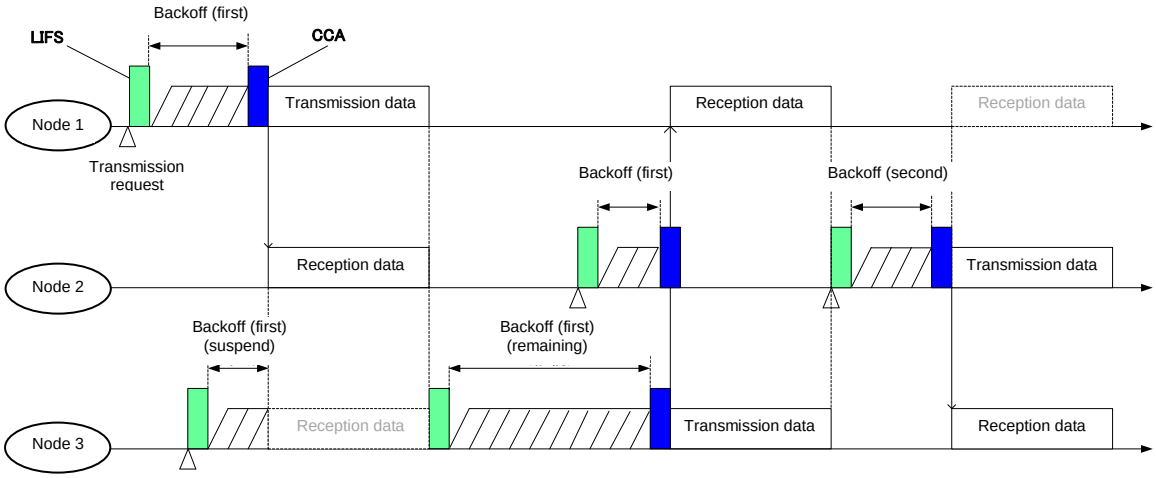


Figure 5-16: CSMA-CA algorithm including retry for data frame transmission

5.9.3.3.3. Backoff operation

The backoff operation in this specification is shown in **Figure 5-17**. (The figure clarifies the operation, based on the description in [802.15.4] 5.1.1.4 CSMA-CA algorithm.)



No	Transmission operation	Description
1	Node 1	Idle at CCA after backoff (first) → Transmission
2	Node 2	Busy at CCA after backoff (first) → Waiting for idle (Receives data if possible.) *1 → Idle at CCA after backoff (second) → Transmission
3	Node 3	Data reception during backoff (first) → Transition to idle after data reception → Idle at CCA after remaining backoff (first) (expiration of remaining backoff time) → Transmission

In this figure, the ACK frame is omitted.

*1: If the busy state is detected during CCA, whether to reception data depends on the used PHY.

Figure 5-17: Backoff operation

5.9.3.3.4. Transmission time management function

(1) Pause duration management

A pause duration shall be provided, based on [T108].

(2) Total transmission time management

[T108] specifies that the sum of the transmission time per hour for a data frame shall be within 360[s]. A function for conforming to this specification shall be provided.

5.9.3.3.5. MAC constants and variables

(1) MAC constants

The MAC constants in this specification are shown in **Table 5-28**. (This table specifies the nominal values, based on [802.15.4g] Table 51 and Table 71.)

Table 5-28: MAC constants

Constant	Description [unit]	Value (nominal) *1	Remarks
phyCCADuration	Carrier sense duration [μsec]	130	
aTurnaroundTime	Turnaround time between transmission and reception [μsec]	1000	
RX to TX TurnaroundTime (=tack)	Turnaround time from reception to transmission [μsec]	300 or more, 1000 or less	
TX to RX TurnaroundTime	Turnaround time from transmission to reception [μsec]	Less than 300	
macMinLIFSPeriod	Minimum LIFS [μsec]	1000	See Section 5.9.3.3.1.
aUnitBackoffPeriod	Backoff unit period [μsec]	1130	See Section 5.9.3.3.1.
macAckWaitDuration	Time to wait for an ACK frame after the completion of data frame transmission [ms]	5	See Section 5.9.3.3.1.

*1: For the error range of each value, see [802.15.4], [802.15.4e], and [802.15.4g].

(2) MAC variables

The MAC variables in this specification are shown in **Table 5-29**. (This table specifies default values, based on [802.15.4] Table 52.)

Table 5-29: MAC variables

Variable	Description	Range	Default value	Remarks
macMaxBE	Maximum backoff exponent	3 to 15 *1	8	
macMinBE	Minimum backoff exponent	0 to macMaxBE	8	
macMaxCSMABackoffs	Maximum number of backoffs	0 to 5	4	
macMaxFrameRetries	Maximum number of retries	0 to 7	3	

*1: The upper limit is specified to 15 to increase the waiting time range (however, the default value is set to 8 within the specification range).

5.9.4. Interface part

5.9.4.1. Overview

The interface part in the recommended specification for single-hop smart meter-HEMS communication shall be compliant with Section 5.5 unless otherwise specified in the following sections.

5.9.4.2. Adaptation layer

The smart meter and HEMS shall be compliant with Section 5.5.3.

5.9.4.2.1. Fragmentation

The smart meter and HEMS shall be compliant with Section 5.5.3.1.

5.9.4.2.2. Header compression

The smart meter and HEMS shall be compliant with Section 5.5.3.2.

5.9.4.2.3. Neighbor discovery

The smart meter and HEMS shall not support neighbor discovery in Section 5.9.4.2.3 in Section 5.5.3.3 based on 6LoWPAN-ND since they use IPv6-based neighbor discovery as described in Section 5.5.3.3. For IPv6-based neighbor discovery, see the next section (Network layer).

5.9.4.3. Network layer

The smart meter and HEMS shall be compliant with Section 5.5.4.

5.9.4.3.1. IP addressing

The smart meter and HEMS shall be compliant with Section 5.5.4.1.

5.9.4.3.2. Neighbor discovery

The smart meter and HEMS shall be compliant with Section 5.5.4.2.

5.9.4.3.3. Multicast

The smart meter and HEMS shall be compliant with Section 5.5.4.3.

5.9.4.4. Transport layer

The smart meter and HEMS shall be compliant with Section 5.5.5.

5.9.4.5. Application layer

The smart meter and HEMS shall be compliant with Section 5.5.6.

5.9.5. Security configuration

5.9.5.1. Overview

In this specification, security configuration shall be conducted according to Section 5.6.

5.9.5.2. Authentication

Compliant with Section 5.6.2. In this specification, the smart meter shall be a PAA and the HEMS shall be a PaC.

5.9.5.2.1. PANA

Compliant with Section 5.6.2.1.

5.9.5.2.2. EAP

Compliant with Section 5.6.2.2.

5.9.5.3. Key update

Compliant with Section 5.6.3.

5.9.5.3.1. PANA key derivation function

Compliant with Section 5.6.3.1.

5.9.5.3.2. EAP-PSK key derivation function

Compliant with Section 5.6.3.2.

5.9.5.3.3. MAC layer key derivation function

Security keys used in the MAC layer shall be derived using the EMSK derived as the result of EAP-PSK negotiation. First, the SMMK, master key for generating MAC layer keys, is generated using the USRK derivation function [USRK] and the SMK-SH, MAC layer key between the smart meter and HEMS is derived from the SMMK.

SMMK = KDF(EMSK, "Wi-SUN JP Route B" | "¥0" | optional data | length)
- optional data = NULL(0x00)
- length = 64

SMK-SH = KDF(SMMK, "Wi-SUN JP Route B" | "¥0" | optional data | length)
- optional data = EAP ID_P | EAP ID_S | IEEE802.15.4 Key Index
- length = 16

As the KDF, the same key derivation function as for PANA, that is, prf+() using PRF_HMAC_SHA2_256 is used. The value of length in optional data required for generating the SMMK and SMK-SH is an unsigned 8-bit integer. The IEEE 802.15.4 Key Index is the lower 8-bit value of the SMMK KEY ID (32-bit MSK Identifier in the Key-Id AVP given by the PAA in the PANA session). For this reason, the PAA shall not assign consecutively MSK Identifiers that have the same lower 8-bit value to the same PaC.

The MAC layer key (SMK-SH) is derived from the master key (EMSK) shared between the smart meter and HEMS as successful authentication by PANA. For this reason, there is a one-to-one connection between the smart meter and HEMS.

5.9.5.4. Encryption and manipulation detection

Compliant with Section 5.6.4.

5.9.5.5. Protection from replay attacks

Compliant with Section 5.6.5.

5.9.6. Recommended network configurations

The smart meter and HEMS use an 8-octet network identifier. This ID is used for association between the smart meter and HEMS. This specification assumes that this ID is set on the smart meter and HEMS in advance. The specification also assumes that the NAI and authentication key required for PANA/EAP are set on the smart meter and HEMS in advance in the same way.

The smart meter shall determine a radio channel to use and PAN ID for constructing a network following the procedure below.

1-1: Data link layer configurations (smart meter)

The smart meter selects a radio channel and detects a PAN ID using Energy Detection Scan (ED Scan) and Enhanced Active Scan. Selection criteria of the radio channel and PAN ID is out of scope of this profile.

1-2: Network layer configurations (smart meter)

The smart meter determines its own IPv6 link local address according to the description in [SLAAC]. After the smart meter has constructed a network in which it acts as the coordinator, the HEMS sets the following data link layer and network layer configurations to connect itself to the home smart meter.

2-1: Data link layer configurations (HEMS)

The HEMS detects the smart meter to connect using Enhanced Active Scan.

2-2: Network layer configurations (HEMS)

The HEMS determines its own IPv6 link local address according to the description in [SLAAC].

The HEMS calculate the IPv6 link local address of the smart meter from the source MAC address in the enhanced beacon from the smart meter. And, the HEMS requests network authentication by the PANA based on the NAI and authentication key, which are shared in advance. The smart meter establishes a PANA session with the HEMS and determines whether to authenticate the HEMS based on the NAI and authentication key, which are shared in advance. When authentication succeeds, the smart meter and HEMS exchange unique key information for communication and use the shared key information for communication as the MAC layer encryption key.

After encrypted communication between the smart meter and HEMS is established, communication between the smart meter and HEMS using encrypted messages starts. The HEMS conducts service discovery using the ECHONET Lite protocol and the smart meter notifies the HEMS of meter readings every 30 minutes.

5.9.6.1. Construction of a new network

Once turned on, the smart meter constructs a new network compliant with the profile. This procedure is the same as that described in Section 5.6.2. The procedure for network construction and joining to this network is shown in **Figure 5-18**.

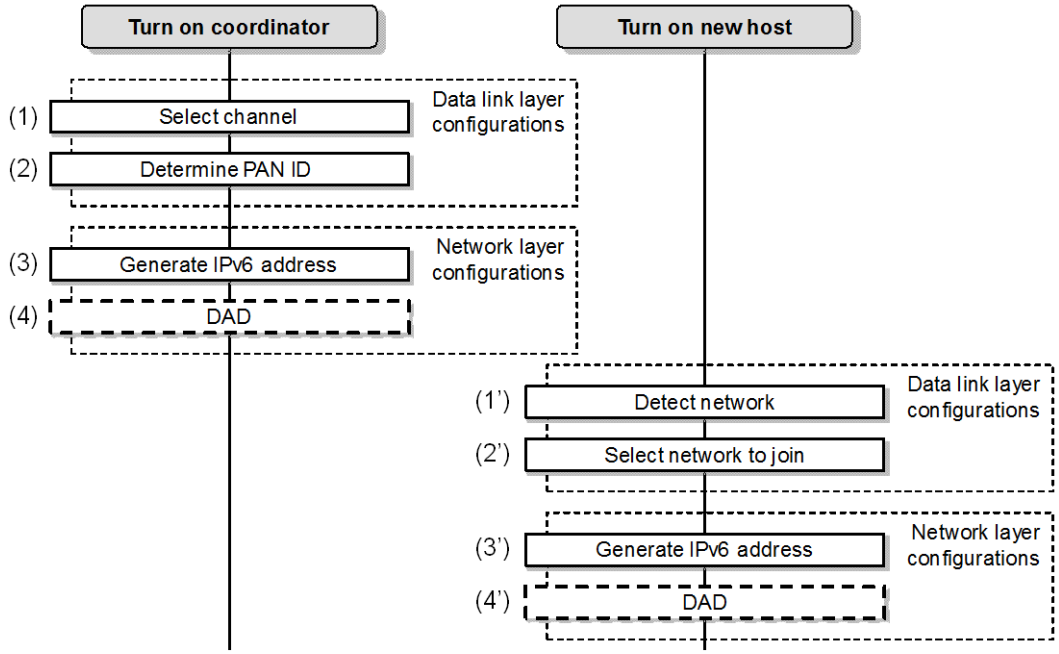


Figure 5-18: Overview of network configuration and joining procedure

5.9.6.1.1. Data link layer configurations

Data link layer configurations for the coordinator are the same as described in Section 5.8.2.1. However, the smart meter uses Enhanced Active Scan and sets no information in the Information Element field.

To detect a smart meter network, the HEMS uses Enhanced Active Scan and sets MLME IE in the Information Element field. As a response to the Enhanced Beacon Request command from the HEMS, the smart meter returns an enhanced beacon in which the same MLME IE is contained in the Information Element field. The association procedure is omitted. Other data link layer configurations for the HEMS are the same as described in Section 5.8.3.1.

Additional information related to these configurations is shown in **Table 5-30**.

Table 5-30: MLME IE sub-ID allocation

Sub-ID value	Content length	Name	Description
0x68	Variable	Unmanaged (network identifier)	Sub-ID used by the HEMS to identify the target meter. Defined for this recommended communication specification.

5.9.6.1.2. Network layer configurations

The smart meter uses the IPv6 link local address only. Other network layer configurations for the smart meter are the same as described in Section 5.8.2.2.

In the same way, the HEMS also uses the IPv6 link local address only. Other network layer configurations for the HEMS are the same as described in Section 5.8.3.2.

The authentication procedure is described in Section 5.9.6.3.

5.9.6.2. IP address detection

Before the authentication procedure by the PANA, the HEMS calculates the IPv6 address of the smart meter. As a way for mutual address resolution, the HEMS estimates the IPv6 link local address using the MAC address in the enhanced beacon from the smart meter.

The MAC address is used to determine the IPv6 address, so neighbor discovery specified in [ND] may not be conducted.

5.9.6.3. Authentication and key exchange

The HEMS conducts security configurations after data link layer and network layer configurations. In other words, the HEMS acting as a PaC initiates a PANA session with the smart meter acting as the PAA.

5.9.6.4. Application layer

As described in Section 5.5.6, ECHONET Lite is used as the application layer and the compound data format is supported. For details, see [SMHEMSIF].

5.9.7. Usage of credentials (supplementary information)

In a Japanese Route-B (smart meter-HEMS) network, Route-B specific credentials (**Table 5-35**) are defined. From this point of view, this section describes how to use the credentials in the communication protocol.

Table 5-35: Route-B credentials

Name	Description
Route-B authentication ID	Unique ID used to associate a specific smart meter with the HEMS. 32-digit character string consisting of ASCII characters 0 to 9 and A to F (32 octets). In this specification, the ID is converted to an ID used by the PANA (EAP-PSK) (in [NAI] format) and network identifier according to the rules described below.
Password (for Route-B authentication)	Password linked to the Route-B authentication ID (12-digit character string consisting of ASCII characters 0 to 9, a to z, and A to Z). This password is used to generate a PSK used by [EAP-PSK] according to the rules described below.

5.9.7.1. Conversion of a Route-B authentication ID to EAP authentication information

NAIs used for EAP identifiers (ID_S and ID_P) are generated based on a 32-digit Route-B authentication ID according to the following rules.

[NAI generation rules]
Smart meter NAI (EAP ID_S): "SM" + "Route-B authentication ID" (34 octets)
HEMS NAI (EAP ID_P): "HEMS" + "Route-B authentication ID" (36 octets)

Example:
When the Route-B authentication ID is "0023456789ABCDEF0011223344556677"
Smart meter NAI (EAP ID_S): "SM0023456789ABCDEF0011223344556677"
HEMS NAI (EAP ID_P): "HEMS0023456789ABCDEF0011223344556677"

5.9.7.2. Conversion of a password to a PSK

A PSK used by EAP-PSK is generated according to the following rules.

[PSK generation rules]
A 16-octet PSK is generated based on the password linked to a Route-B authentication ID using the following PSK generation function (PSK_KDF).

PSK = PSK_KDF(password)
= LSBytes16(SHA-256(Capitalize(password))
(16 lower-order octets of the output created by capitalizing the password character string and hashing it using SHA-256)

Example:
When the password is "0123456789ab"
PSK = LSBytes16(SHA-256("0123456789AB"))
= 0xf58d060cc71e7667b5b2a09e37f602a2

5.9.7.3. Conversion of a Route-B authentication ID to a network identifier

The HEMS conducts Enhanced Active Scan using the IEs field to detect the home smart meter. The HEMS transmits an enhanced beacon request with setting MLME IE (Group ID = 0x1) in the Payload IEs field and 8 lower-order octets (network identifier) of the Route-B authentication ID the HEMS has in IE Contents of Sub-ID = 0x68 (Unmanaged). When the received network identifier is the same as the network identifier the smart meter has, the smart meter returns an enhanced beacon as a response. This enhanced beacon is transmitted for unicast and contains the same information in the enhanced beacon request from the HEMS in the Payload IEs field. Through the data exchange above, the HEMS and smart meter confirms that they have the same ID, and the HEMS initiates a PANA session with the smart meter. (**Figure 5-19**)

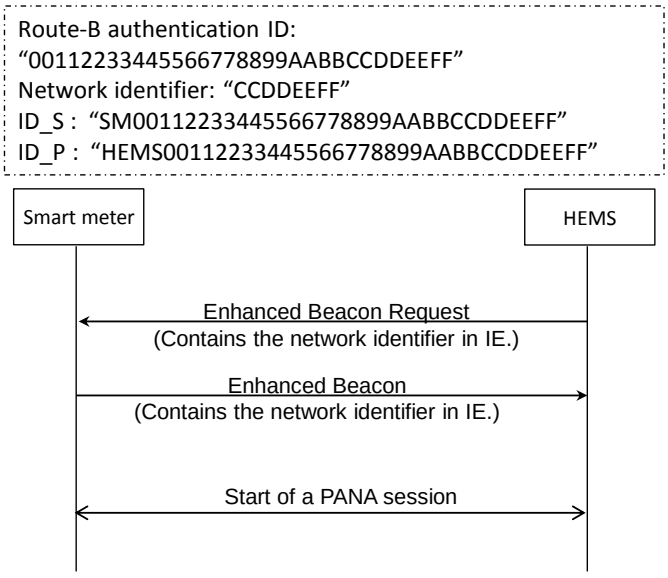


Figure 5-19: Smart meter discovery procedure

5.9.8. Specifications for the device/physical layer/MAC layer to implement the recommended specification

See Sections 5.9.2 and 5.9.3.

6. System B

This chapter describes the ZigBee IP specification supporting 920MHz IPv6 specified in [ZIP]. To obtain official ZigBee certification, see also [ZIP]. ZigBee IP may be referred to as ZIP in this chapter.

For system B, the following three node types shall be specified: ZIP coordinator, ZIP router, and ZIP host. A ZIP coordinator plays a role in managing a network. A ZIP router has a forwarding function in a multihop network. A star single-hop network can be constructed with a ZIP coordinator and ZIP host. A multihop network can be constructed with a ZIP router in addition to them. The protocols to implement for these three types of nodes are specified in [ZIP]. The user can use these protocols in combination according to the purpose. This system does not need to customize the protocol stack according to the network configuration for each vendor, which provides high interoperability.

Due to good 920MHz radio propagation, in a small home, a single-hop network may be able to be constructed. However, cases where radio waves are not reached via a single-hop network are reported, depending on the device installation location and design condition, for example, when a built-in small antenna is used, a device is installed behind or in a home electrical appliance or another metallic product, or a device is installed in an outdoor facility. In these cases, system B that can support a multihop network is effective.

For system B, a function for improving the security and link stability has already been specified, and system B is only one among the three systems that uses a global address, which provides high connectivity with other home IP systems and external IP networks.

In addition, for the network layer in system B, not only the IETF standards are referenced, but also specifications are added to ensure interoperability. Implementation according to this chapter will improve interoperability. By obtain certification from ZigBee Alliance, interoperability with other systems is guaranteed.

6.1. Overview

6.1.1. Purpose

The purpose of the ZigBee IP specification is to define a standard, interoperable protocol stack using IETF-defined networking protocols for use in IEEE 802.15.4-based wireless multihop networks.

6.1.2. Scope

This chapter contains the specification for the ZigBee IP protocol stack for use in ECHONET Lite.

This standard uses IETF and IEEE specifications. This chapter describes changes to these specifications (including the use of a mandatory function as an optional function and the use of an optional function as a mandatory function).

6.1.3. Overview of the protocol stack

The ZigBee IP protocol stack is illustrated in the figure below.

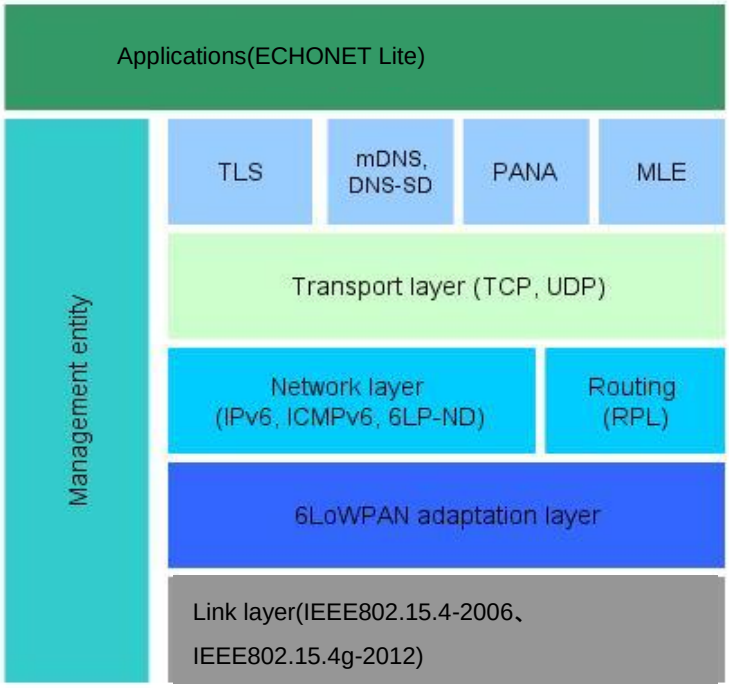


Figure 6-1: ZigBee IP protocol stack

The data link layer provides the following services:

- Discovery of an IEEE 802.15.4 PAN in radio propagation range
- Transmissions with the maximum MAC payload size (specified separately). The actual MAC payload in each frame differs depending on the mode, security options, and addressing.
- Support for frame transmissions to sleeping devices using frame buffering and polling
- Frame security including encryption, authentication, and replay protection. Note that key management is not performed in this layer.

The 6LoWPAN adaptation layer provides the following services:

- IPv6 and UDP header compression and decompression
- Fragmentation and reassembly of an IPv6 packet that exceeds the maximum payload size available in the data link layer frame

The network layer provides the following services:

- IPv6 address management and packet framing
- ICMPv6 messaging
- Router and neighbor discovery
- IPv6 stateless address autoconfiguration and duplicate address detection (DAD)
- Propagation of 6LoWPAN configuration information
- Route computation and maintenance using the RPL protocol
- IPv6 packet forwarding

- IPv6 multicast forwarding within the subnet

The transport layer provides the following services:

- Guaranteed and non-guaranteed packet delivery service
- Multiplexing of packets to multiple applications

The management entity is a conceptual function that is responsible for invoking and managing various protocols to achieve the desired operational behavior by the node. It is responsible for:

- Node bootstrapping process
- Node power management
- Non-volatile storage and restoration of critical network parameters
- Authentication and network access control using PANA protocol
- Network-wide key distribution using PANA protocol
- Propagation of network configuration parameters using MLE protocol

6.1.4. Document organization

The rest of the document is organized as follows. Section 6.2 contains the ZigBee IP protocol specification. It describes the various IEEE and IETF standard protocols that must be supported by a ZigBee IP implementation along with details on the mandatory and optional functions within each of them. Section 6.3 describes the functional behavior of a ZigBee IP node during various stages of network operation. Section 6.4 contains informative material and examples of protocol message exchanges that may be useful for implementation of this specification.

Change conditions for 920MHz support are found in Section 6.6. The implementation specifications for the physical and data link layers are given in Section 6.7.

Some external documents are referenced as a document specified in this chapter, for example, [802.15.4] listed in Chapter 3 Reference Standards and Documents and others are directly referenced with its well-known document number specified by an organization such as IETF, for example, [RFC 4944].

6.2. Protocol specification

6.2.1. Physical layer

A ZigBee IP node must support at least one physical interface conforming to one of the physical specifications defined in IEEE 802.15.4-2006, [802.15.4], and IEEE 802.15.4g-2012.

This standard supports only a single physical interface and does not support multiple physical interfaces.

6.2.2. Data link layer

A ZigBee IP node must implement the data link layer specification in IEEE 802.15.4-2006 [802.15.4]. A ZIP host must implement at least the RFD (reduced function device) function. On the other hand, a ZIP router and ZIP coordinator must implement the FFD (full function device) function.

A ZIP node is not required to implement all available data link functions. Specifically, the beacon mode and guaranteed timeslots (GTS) functions are not required for ZigBee IP networks. The Association and Disassociation command frames are not required to be supported.

A ZIP node must support the data link layer security functions described in Section 6.4 in this document.

A ZigBee IP node must support the 64-bit and 16-bit data link layer addressing modes. An EUI-64 address must be

configured in each device at manufacture time. This address is globally unique and it is expected that this address is fixed during the lifetime of the device. A 16-bit short address must be assigned to each device after it has completed network admission. This address is unique within that particular IEEE 802.15.4 PAN.

6.2.3. Adaptation layer

The adaptation layer using 6LoWPAN is defined by standards produced by the 6LoWPAN Working Group of the IETF.

The encapsulation of IPv6 packets in IEEE 802.15.4 frames must be performed as specified in [6LOWPAN] and [6LPHC]. The mesh addressing header is not required to be supported as ZigBee IP does not use the link-layer mesh-under routing configuration described in [6LOWPAN] and instead relies on the route over configuration.

6.2.3.1. 6LoWPAN fragmentation

The 6LoWPAN fragmentation scheme defined in [6LOWPAN] must be supported.

The fragments composing a single IP datagram must be transmitted in order of increasing datagram_offset. In addition, the transmission of fragments of one datagram must not be interleaved with any other datagrams fragmented or otherwise, to the same destination. (While [6LOWPAN] allows fragments and packets to be transmitted in any order, having fragments arrive in order and not interleaved during reassembly simplifies both data reassembly and detection of missing fragments. The physical and data link layers used for ZigBee IP do not themselves reorder packets, so the above restrictions are sufficient to ensure in-order packet arrival.)

The link MTU for the 6LoWPAN interface must be set 1280 octets (see Section 6.2.4.3 for exceptions).

6.2.3.2. Header compression

The 6LoWPAN header compression scheme defined in header compression [6LPHC] must be supported by a ZigBee IP node. A ZigBee IP node must support all compression modes defined in [6LPHC]. When an IPv6 packet is transmitted, the most effective compression scheme should be used to minimize the size of the transmitted packet. A node should be able to receive an IPv6 packet with any or no header compression as long as the header is encoded using the format defined in [6LPHC].

[6LPHC] specifies the use of pre-defined context identifiers for the purpose of compressing IPv6 addresses. These context identifiers are defined at the 6LBR and conveyed to the other nodes in the network via router advertisements [6LPND].

The 6LBR in a ZigBee IP network must not define more than MIN_6LP_CID_COUNT context identifiers for purposes of IP header compression. It must define the default context identifier (context zero) and set its value to the IPv6 prefix assigned to the 6LoWPAN, as defined in Section 6.1.

All other ZIP nodes must support the configuration and use of at least MIN_6LP_CID_COUNT context identifiers for purposes of IPv6 header compression.

6.2.3.3. Neighbor discovery

The neighbor discovery protocol must be implemented as defined in 6LoWPAN neighbor discovery specification [6LPND].

A ZigBee IP node must support the optional mechanisms defined in [6LPND] for multihop distribution of prefix and context information.

A ZigBee IP node must support the optional mechanisms defined in [6LPND] for multihop duplicate address

detection.

A ZigBee IP node should suppress neighbor unreachability probes as the upper layer protocols specified in later sections include periodic packet transmissions that detect the bidirectional reachability of neighbor nodes as well as detecting new neighbor nodes. However, all nodes must respond appropriately to a neighbor unreachability probe.

6.2.4. Network layer

A ZigBee IP node must support the IPv6 protocol [IPv6].

A ZigBee IP node is not required to support Authentication Header (AH) and Encapsulating Security Payload (ESP) IPv6 extension headers and this mode of operation is not described in this standard.

A ZigBee IP node is not required to support the Fragment IPv6 extension header.

A ZigBee IP node must support the ICMPv6 protocol [ICMP6]. Nodes must support the ICMPv6 error messages as well as the echo request and echo reply messages.

6.2.4.1. IP addressing

All ZigBee IP nodes must support the IPv6 addressing architecture specified in [IP6ADDR].

A ZigBee IP network will be assigned one or more /64-bit prefix(es), which will be announced as the prefix(es) throughout the entire 6LoWPAN (see [6LPND]). These prefix(es) may be either ULA [ULA] or GUA prefix(es). A node must be capable of supporting at least MIN_6LP_PREFIX prefixes. For consistency with [ND], [6LOWPAN], and other standards, the 6LoWPAN prefix(es) must always be /64 bits long. A 6LoWPAN node can use either its EUI-64 address or its 16-bit short address to obtain the interface identifier, as defined in Section 6 of [6LOWPAN]. When the 16-bit short address is used to construct the interface identifier, the method specified in [6LPHC] must be followed. When applied to header compression modes that are based on the 16-bit short address, the /64-bit prefix from the default context and the additional 48 bits that convert the 16-bit short address to a 64-bit IID are elided from the compressed address.

A ZigBee IP node must configure its IEEE 802.15.4 interface with at least the following addresses:

- A 128-bit link-local IPv6 address configured from the EUI-64 of the node as the interface identifier using the well-known link-local prefix FE80::0/64 as described in [SLAAC] and [6LOWPAN]. When this type of address is compressed using [6LPHC], it must be considered stateless compression. This type of address is known in its abbreviated form as LL64.

- A 128-bit link-local IPv6 address configured from the interface identifier based on the 16-bit short address of the node using the well-known link-local prefix FE80::0/64 as described in [SLAAC] and [6LOWPAN]. When this type of address is compressed using [6LPHC], it must be considered stateless compression. This type of address is known in its abbreviated form as LL16.

- One or more 128-bit unicast IPv6 address(es). The interface identifier used for address configuration is based on the 16-bit short address of the node. The prefix is the ULA or GUA prefix obtained from the 6LoWPAN Prefix information option (PIO) in the router advertisement ([6LPND]). If multiple global prefixes are advertised, the node may choose to configure addresses with any or all of them based on local node policy. When this type of address is compressed using [6LPHC], it must be considered stateful, context based compression. This type of address is known in its abbreviated form as GP16.

In addition, all nodes must join the appropriate multicast addresses as required by [ND].

DAD must not be performed on addresses configured from an EUI-64 interface identifier, as recommended in [6LPND]. The GP16 address configured from the 16-bit short address must be tested for uniqueness using the DAD mechanism [6LPND].

6.2.4.2. Routing protocol

All ZigBee IP routers must implement the RPL routing protocol [RPL]. RPL establishes a destination oriented directed acyclic graph (DODAG) toward a root node, called the DODAG root. Packets are directed up the DODAG toward the root using this graph. Packets are directed from the root down the DODAG using routes established from Destination Advertisement Object (DAO). The following subsections describe how RPL is used in ZigBee IP to ensure compatibility between devices.

A ZigBee IP network may run multiple RPL instances concurrently. Only global instances should be used. The LBR node must start an RPL instance. Other ZigBee IP routers may start their own RPL instance if they offer connectivity to an external network or if they are administratively configured to do so. In this case, the RPL instance identifier should be selected so that it does not conflict existing identifiers. This means that the router should first join the network and discover existing RPL instances before starting its own RPL instance. The presence of DIOs with different DODAG id fields but equal instance id fields indicates a duplicate instance id. If a DODAG root detects an instance id conflict with its instance, it should reform the DODAG using a different instance id.

A ZigBee IP router must be capable of joining at least MIN_RPL_INSTANCE_COUNT RPL instances and should join all RPL instances that are available in the network subject to its memory constraints.

If a node loses connectivity to an RPL instance (that is, it cannot find a parent with finite rank) for over RPL_INSTANCE_LOST_TIMEOUT seconds, it should delete the instance. This may happen, for example, if the root of the instance is replaced.

Each DODAG root may be configured to include zero or more prefixes in the Route Information Option (RIO). Note that if the root wishes to advertise the default route (prefix 0::), it must include it in an RIO. The absence of any RIO prefixes indicates that the DODAG can route packets only to the root node. If the DODAG root is also the Authoritative Border Router [6LPND], it must include the PIO information in both the RPL DIO packet as well as the Router Advertisement packet.

In a ZigBee IP network, an RPL instance must contain a single DODAG with a single root. A DODAG root must always be grounded. Floating DODAG must not be used.

RPL control messages are transmitted using "unsecured" RPL security mode. Link layer security is used to meet the security requirements.

In a ZigBee IP network, only the non-storing RPL mode of operation is used. In the non-storing mode, all downward routes are managed by the DODAG root as source routes. Routers transmit DAO messages containing downward route information directly to the root, with the DAO-ACK ('K') flag enabled. DAO messages are not delayed at each hop (see [RPL] section 9.5). DAO messages should be jittered by the originating router to avoid multiple nodes transmitting simultaneously to the root. Multicast DAO messages are not used in a ZigBee IP network.

Every non-root router should be capable of having at least RPL_MIN_DAO_PARENT parents per DODAG, to be used for upward routing by the router itself, and downward routing by the root.

Metric Container and RPL Target Descriptor options must not be included in any RPL control messages.

6.2.4.2.1. Host participation in RPL

A ZIP host does not participate in the RPL protocol.

6.2.4.2.2. Objective function

The objective function defines the route selection objectives within an RPL instance. The objective function is identified by the objective code point (OCP) field in the DODAG configuration option.

A ZigBee IP router must implement the MRHOF objective function [RPL-MRHOF] using the ETX metric, without metric containers.

ZigBee IP routers must use the Mesh Link Establishment protocol [MLE] to determine the ETX of links to neighbor routers. Routers estimate the incoming delivery ratio for each neighbor node in their neighbor table. The estimation method depends on the implementation. The inverse of the incoming delivery ratio is then communicated to the neighbor via the MLE Neighbor TLV. The ETX of the link is equal to the product of the forward and reverse inverse incoming delivery ratios.

MRHOF parameters must be set as follows:

MAX_LINK_METRIC: 16 * MinHopRankIncrease.

MAX_PATH_COST: 256 * MinHopRankIncrease.

MIN_PATH_COST: 0.

PARENT_SWITCH_THRESHOLD: 1.5 * MinHopRankIncrease.

PARENT_SET_SIZE: 2.

ALLOW_FLOATING_ROOT: 0.

6.2.4.2.3. RPL configuration

This section specifies the RPL configurations and RPL control messages used by ZigBee IP. Any unspecified configurations are used as defined in [RPL].

The DODAG root is authoritative for setting some information through DIO and the information is unchanged during propagation toward leaf nodes. This information is described below:

1. RIO(s) (if any)
2. DODAG configuration option
3. PIO(s) (if any), with the exception that if the 'R' flag is set, the last two octets of the IPv6 address (link layer short address) in the Prefix field will change.
4. RPLInstanceID
5. DODAGID
6. DODAGVersionNumber
7. Grounded flag
8. Mode of operation field

6.2.4.2.3.1. DODAG Information Solicitation (DIS) frame format

The DIS messages may include the Pad1, PadN, or Solicited Information options.

A ZIP router may transmit a DIS message with the Solicited Information option and the InstanceID predicate in

order to limit the DIO response to a specific RPL instance.

6.2.4.2.3.2. Multicast DODAG Information Object (DIO) frame format

A multicast DIO message contains the DIO base object and the RIO objects.

The configuration of the DIO base is as follows:

- The RPLInstanceID should be set to a global instance with a value in the range of [0x00, 0x7F].
- The Version Number should be initialized to a value of 0xF0.
- Grounded (G): The Grounded flag of the DIO must always be set. ZIP nodes must not create floating DODAGs.
- Mode of Operation (MOP): The Mode of Operation (MOP) field in the DIO must be set to 0x01. This indicates the non-storing mode in RPL.
- DODAGPreference: The DODAGPreference field should be set to 0. ZIP routers are not required to implement DODAG preference based on this field.
- Destination Advertisement Trigger Sequence Number (DTSN) - The root node increments the DTSN field of the DIO when it wishes to receive fresh DAO messages from the network without incrementing the DODAG version number. ZIP routers must set their DTSN counter to the same value as their parent router and update it whenever the parent router updates its value. This way the root node can increment the value in its DTSN field and propagate that change through the entire DODAG.

The configuration of the RIO is as follows:

- The Prefix Length should be set to the length of the prefix for which the route is being advertised.
- The Route Preference (Prf) value should be set to 0 (medium) preference or administratively configured.
- The prefix should be set to the value for which the route is being advertised.

RPL allows the root to include multiple RIO options in a DIO frame to advertise external routes that are reachable through the root. A ZIP node operating as an RPL root should limit the number of RIO options included in the DIO packet to RPL_MAX_RIO. This is to ensure that all ZIP routers can process the necessary route information. Similarly, an RPL root should limit the number of PIO options included in the DIO packet to RPL_MAX_PIO.

6.2.4.2.3.3. Unicast DODAG Information Object (DIO) frame format

A unicast DIO message contains the DIO base, RIO(s), PIO(s), and DODAG configuration option. The DIO base and RIO used in unicast messages have the same format as in multicast messages.

The configuration of the PIO is as follows:

- The Prefix Length must be set to 0x40, indicating a 64-bit prefix.
- The 'L' flag (on-link flag) must not be set (see [6LPND] 6.1).

- The 'A' flag (autonomous address-configuration flag) must be set if the prefix can be for stateless address autoconfiguration.

- The 'R' flag (router address flag) must be set if the node has configured an address with this prefix. Otherwise, it must not be set.

- The Prefix field must contain the routable IPv6 address of the source node.

The configuration of the DODAG configuration option is as follows:

- The Authentication Enabled (A) flag must not be set. ZigBee IP does not use RPL security and instead relies on data link layer security.

- The Path Control Size (PCS) field must be set to 2. This controls the number of DAO parents and that of downward routes that are configured for a ZIP node.

- The trickle parameters that govern the DIO transmission should be set by the RPL root. The parameters should be set to balance the amount of traffic generated by the trickle timer reset against the joining startup time. The following parameter values are recommended:

    - The DIOIntervalDoublings value should be set to 12.

    - The DIOIntervalMin value should be set to 9.

    - The DIORedundancyConstant value should be set to 3.

    The ZIP routers must configure their internal DIO trickle timer parameters based on the incoming DODAG configuration option and must not hardcode the above recommended values.

- The MaxRankIncrease field should be set to a value other than 0. MaxRankIncrease is used to configure the allowable rank increase in support to local repair. If it is set to 0, local repair is disabled. A typical value for this field would be about 16 and a larger value should be in networks with more hops.

- The MinHopRankIncrease field should be set to 0x80.

- The Object Code Point (OCP) must be set to the assigned value in [RPL-MRHOF].

6.2.4.2.3.4. Destination Advertisement Object (DAO) frame format

A unicast DAO request is transmitted to the DODAG root node in order to establish the downward routes. This request is composed of the DAO base, RPL target option(s), and Transit Information option(s).

The configuration of the DAO base is as follows:

- RPLInstanceID: Must be a global RPLInstanceID which must be in the range [0x00, 0x7F].

- 'K' flag: Should be set. This flag indicates that the DODAG root is expected to transmit a DAO-ACK back.

- 'D' flag: Must be cleared as local RPLInstanceIDs are not used.

- The DAOSequence should be initially set to 0xF0 and incremented in a "lollipop" fashion afterwards. A node should increment the DAO sequence number when it retransmits a DAO due to lack of DAO-ACK.

At least one RPL target option must be present in the DAO request. The RPL target option is used to inform the DODAG root that a route to the target IPv6 address exists.

The configuration of the RPL target option is as follows:

- The Prefix Length should be set to "0x80" since an IPv6 address is present in the target prefix.
- The target prefix should be set either to the IPv6 address of the ZIP router that is transmitting the DAO packet to the DAO router or to the IPv6 address of a ZIP host that is directly reachable by that router.

The Transit Information option is used to indicate the DODAG parents to the DODAG root. The configuration of the Transit Information option is as follows:

- The External (E) flag must be set to 0 when the target prefix contains the IPv6 address of the ZIP router that is transmitting the DAO packet. Otherwise, it must be set to 1.
- The Path Control field is used for limiting the number of DODAG parents included in a DAO request and for setting a preference among them.
- The Path Sequence should be updated for each new DAO packet.
- The Path Lifetime must be set to the lifetime for which the DAO parent is valid. It must be set to zero when the ZIP router wants to delete an existing DAO parent from its downward routing table entry at the DODAG root.
- A single parent address must be present in the Transit Information option and it must contain the IPv6 address of the DODAG parent or the IPv6 address of the node generating the request when a DAO is transmitted on behalf of the host. Multiple parent addresses may be conveyed using multiple Transit options.

The RPL root determines the freshness of the routing information received through a DAO packet before updating its source route entries. When the DAO carries route information for host nodes, indicated by the setting of the 'E' flag, the root must use time-of-delivery as the freshness indicator. That is, a DAO that arrives latter in time is assumed to contain more recent route information. Otherwise, the root is free to determine the freshness using a combination of time-to-delivery, DAO sequence, and path sequence values.

6.2.4.2.3.5. Destination Advertisement Object ACK (DAO-ACK) frame format

The DAO-ACK request is transmitted from the DODAG root to the node generating the DAO request. The root must acknowledge each received DAO packet irrespective of its sequence number.

The configuration of the DAO-ACK is as follows:

- The RPLInstanceID field must be set to the instance.
- The 'D' flag should be set to zero as local RPL instances are not used.
- The TDODAGID field is not present when the "D" flag is zero.

6.2.4.3. IP traffic forwarding

A ZIP router may forward unicast packets directly to the destination if the destination node is known to be directly reachable. Otherwise, it should forward unicast packets using the forwarding rules defined in the RPL protocol.

The RPL protocol requires that all data packets forwarded in the RPL domain must contain either the RPL Option [RPL-OPT] or RPL Source Route [RPL-HDR] header.

The Source Routing header may only be inserted by the DODAG root of the RPL instance. The Source Routing is used for ① P2MP (point to multipoint) traffic originating outside the DODAG and delivered through the DODAG root and for ② P2P (point to point) traffic, which is forwarded from the source up the DODAG to the root and then forwarded back down the DODAG to the destination. The DODAG root will use the node specific routing information developed through information contained in the RPL DAO packets to forward IPv6 traffic to nodes in the DODAG. When the DODAG root initiates transmission or receives an IPv6 datagram with the destination address of one of the nodes in the DODAG, the root will add source routing information to the IPv6 datagram according to [RPL-HDR].

The DODAG root should insert the Source Routing header directly only in the case where it is the source of the IPv6 packet and the destination is within the RPL domain (that is, it is a ZIP router with the same prefix). In all other cases, it must use "IPv6-in-IPv6 tunneling". The tunnel exit point must be set to the address of the final destination address if that node is within the RPL domain. Otherwise, it must be set to the parent address of the destination. The DODAG root determines the parent address from the Transit Information option in the DAO packet that has a Target option corresponding to the destination address.

A ZIP router that is originating a unicast IPv6 packet and forwarding it via the RPL protocol must insert the RPL Option header. The header must be inserted using tunneling in all IPv6 based cases except when the destination address is the DODAG root of the RPL instance used by the packet. In that case, the header may be inserted either directly in the packet or by using "IPv6-in-IPv6" tunneling. When the RPL Option header is inserted using tunneling, the tunnel exit point should be set to the next hop address along the route towards the DODAG root. In the case where the final destination address of the packet is the DODAG root of the RPL instance used by the packet, the tunnel exit point may be set to that address.

A ZIP router that is using RPL to forward a unicast IPv6 packet originated by another node must insert the RPL Option header if the packet does not already contain either the RPL Option header or Source Routing header. The header must be inserted using "IPv6-in-IPv6" tunneling. The tunnel exit point should be set to the next hop address along the route towards the DODAG root. In the case where the final destination address of the packet is the DODAG root of the RPL instance used by the packet, the tunnel exit point may be set to that address.

A ZIP node must ensure that the insertion of an RPL extension header, either directly or via IPv6-in-IPv6 tunneling, does not cause IPv6 fragmentation. This is done by using a different MTU value for packets in which the IPv6 header includes an RPL extension header. The RPL tunnel entry point should be considered as a separate interface whose MTU is set to the 6LoWPAN interface MTU plus RPL_MTU_EXTENSION octets.

A ZIP host node should forward packets to its default parent router (this is the router through which the host has registered its address, as described in [6LPND]). If the parent router determines that the packet needs to be forwarded using the RPL forwarding rules, it inserts the necessary RPL extension header following the rules described above.

6.2.4.4. Multicast forwarding

The multicast scope value of 3 [IP6ADDR] is defined as a "subnet-local" scope that comprises of all links within a single network and all interfaces of ZIP nodes. Thus, a ZIP network forms a subnet-local multicast zone [RFC 4007] with a scope value of 3.

All ZIP nodes must be connected to the subnet-scope-all-nodes multicast group (FF03:0:0:0:0:0:0:1) (consisting of all nodes on the subnet and subnet-scope-all-mpl-forwarders (all MPL forwarding nodes on the subnet) on their ZIP interface. All ZIP routers must be connected to the subnet-scope-all-routers multicast group (FF03:0:0:0:0:0:0:2) (consisting of all routers on the subnet) on their ZIP interface. ZIP nodes may be connected to additional subnet-scope multicast groups based on administrative configuration.

ZIP nodes use the MPL protocol [MPL] for multicast IP packet dissemination. All ZIP nodes must configure the ZIP interface as an MPL interface. All ZIP nodes may originate and receive MPL data messages and ZIP routers may also forward MPL data messages to other nodes.

The MPL protocol requires each forwarding node to participate in at least one MPL domain specified by the subnet-scope-all-mpl-forwarders group. In addition, ZIP nodes must participate in the MPL domains specified by each of the subnet-scope multicast addresses that are subscribed on the ZIP interface.

ZIP nodes must configure the MPL parameters as follows:

- The PROACTIVE_PROPAGATION flag must be set to true. This indicates that MPL forwarding is performed proactively.
- DATA_MESSAGE_IMIN = 512ms
- DATA_MESSAGE_IMAX = 512ms
- DATA_MESSAGE_K = infinite
- DATA_MESSAGE_TIMER_EXPIRATIONS = 0 for ZIP hosts and 3 otherwise
- CONTROL_MESSAGE_TIMER_EXPIRATIONS = 0

Note that setting the DATA_MESSAGE_TIMER_EXPIRATION parameter to 0 on ZIP hosts results in disabling forwarding and retransmission of MPL data messages. Similarly, setting the CONTROL_MESSAGE_TIMER_ EXPIRATION parameter to 0 on all ZIP nodes means that MPL control messages are not transmitted in a ZIP network.

MPL data messages contain the MPL Option in an IPv6 Hop-by-Hop header. ZIP nodes must configure the MPL Option as follows:

- The value of the S field must be set to 1 to indicate that the seed-id is a 16-bit value.

The value of the seed-id field must be set to the MAC short address of the node originating the MPL data message.

6.2.5. Transport layer

6.2.5.1. Connection oriented service

All ZigBee IP nodes must support the TCP (Transmission control protocol) protocol as defined in [TCP].

6.2.5.2. Connectionless service

All ZigBee IP nodes must support the UDP (User Datagram Protocol) protocol as defined in [UDP].

6.2.6. PANA

The Protocol for Carrying Authentication for Network Access [PANA] must be used as the EAP transport for carrying authentication data between a joining node and the Network Authentication Server. This section clarifies the

definitions of constraints and specifications above and beyond those specified in [PANA] and [PANA-ENC].

6.2.6.1. PRF (pseudo random function), message authentication, and encryption algorithms

Only the following algorithm identifiers must be used:

Table 6-1: PANA algorithm identifiers

Algorithm	Type	Value	Comment
PRF	PRF_HMAC_SHA2_256	5	IKEv2 Transport Type 2
AUTH	AUTH_HMAC_SHA2_256	12	IKEv2 Transport Type 3
Encryption	AES-CTR	1	

The proposed PRF and AUTH hash algorithms based on SHA-256 are described in [IKEv2] and detailed in [IPSEC-HMAC]. The proposed Encryption algorithm is used by [PANA-ENC].

6.2.6.2. Network security material

The PANA protocol is used to transport the network security material from the Authentication Server to each authenticated node in the ZigBee IP network. This security material is used by each node to further derive encryption keys that are used to provide security for other protocols. The network security material consists of the following parameters.

Table 6-2: Network security material

Parameter	Size	Comment
Network Key	16 octets	Common network-wide security key that is forwarded using PANA by the Authentication Server to all authenticated ZIP nodes in the network
Key sequence number	1 octet	Sequence number associated with this network key
Node Auth Counter	1 octet	Value of the authentication counter to be used by each node. This parameter is unique for each node in the network.

The Network Key is owned and managed by the Network Authentication Server. Each Network Key has a sequence number which takes a value between 1 and 255. The Network Authentication Server manages updates of the Network key and associated sequence number and defines which Network Key is active.

In addition, the Authentication Server manages an Auth Counter parameter for each node in the network. The combination of the Network Key, Key sequence number, and Auth Counter is transported as a single entity by the Authentication Server to each node.

6.2.6.3. Vendor-specific AVPs

The following ZigBee Alliance vendor-specific "PANA AVPs" are defined to support the transport and update of the network security material. As these are vendor-specific AVPs, as long as they are defined in this document, they shall not be defined or referenced in any other documents.

The private enterprise number (PEN) assigned to the ZigBee Alliance through the IANA is 37244. The assignment is given in the following website: http://www.iana.org/assignments/enterprise-numbers

6.2.6.3.1. Network key AVP

The purpose of this AVP is to securely forward the network security parameters from the Authentication Server to each node.

```
struct PANAAVP {
  uint16 code = 1; /* ZigBee Network Key */
  uint16 flags = 1; /* Vendor-specific */
  uint16 length = 18;
  uint16 rsvd = 0;
  uint32 vendor_id = 37244; /* ZigBee Alliance PEN */
  struct ZBNWKKEY {
    uint8 nwk_key[16]; /* NwkKey */
    uint8 nwk_key_idx; /* NwkKeyIdx */
    uint8 auth_cntr; /* AuthCntr */
  };
  struct AVPPad {
    uint8 bytes[2];
  };
};
```

6.2.6.3.2. Key request AVP

The purpose of this AVP is to allow a PaC to request the PAA to transport either a new network key or an update auth counter for the current network key.

```
struct PANAAVP {
   uint16 code = 2; /* ZigBee Key Request */
   uint16 flags = 1; /* Vendor-specific */
   uint16 length = 2;
   uint16 rsvd = 0;
   uint32 vendor_id = 37244; /* ZigBee Alliance PEN */
   struct ZBNWKKEYREQ {
       uint8 nwk_key_req_flags; /* request flags */
       uint8 nwk_key_idx; /* NwkKeyIdx */
   };
   struct AVPPad {
       uint8 bytes[2];
   };
};
```

6.2.6.4. Timeouts

Retransmission timeout timers are specified in Chapter 9 in [PANA]. The following values should be used.

Table 6-3: PANA timeout values

Parameter	Value	Comment
PCI_IRT	1 sec	Initial PCI timeout
PCI_MRT	120 secs	Maximum PCI timeout value
PCI_MRC	5	Maximum number of PCI retransmission attempts
PCI_MRD	0	Maximum PCI retransmission duration
REQ_IRT	15 sec	Initial Request timeout
REQ_MRT	30 secs	Maximum Request timeout value
REQ_MRC	5	Maximum number of Request retransmission attempts
REQ_MRD	0	Maximum Request retransmission duration

6.2.7. EAP

The Extensible Authentication Protocol (EAP) is an authentication framework which supports multiple authentication methods (known as EAP methods). This section clarifies the definitions of constraints and specifications above and beyond those specified in [EAP].

The ZIP coordinator must function as an EAP authenticator while all other nodes must function as an EAP peer.

6.2.7.1. EAP Identity

The EAP Request/Identity message is optional. However, the EAP Response/Identity must be supported by the client in response to the Request/Identity. The EAP identity (given in a response message to an EAP Request/Identity) must be "anonymous" to prevent any information about the EAP client/peer from being revealed in clear text during the initial transactions of the authentication. The string must not be null-terminated, that is, shall have a length of 9 octets.

6.2.8. EAP-TLS

EAP-TLS represents a specific type of EAP method (see [EAP]). This section clarifies the definitions of constraints and specifications above and beyond those specified in [EAP-TLS].

6.2.8.1. EAP key expansion from the master secret

[EAP-TLS] specifies the key expansion for derivation of keying and IV (Initial Vector) material. This section defines the specific expansion for the cipher suits used and the use of the outputs.

```
MSK = PRF(master_secret, "client EAP encryption", ClientHello.random +
ServerHello.random);
```

The string "client EAP encryption" must not be null-terminated, that is, shall be a length of 21 octets.

The PRF function must be iterated twice as the MSK length is 64 octets and the hash output from SHA-256 is only 32 octets. The EMSK must not be used and therefore does not need to be generated.

The MSK must be used as defined in [PANA] and [PANA-ENC] to generate PANA_AUTH_KEY and PANA_ENCR_KEY.

6.2.8.2. EAP-TLS fragmentation

It is mandatory for EAP-TLS peers and servers to support fragmentation as described in [EAP-TLS] Section 2.1.5. EAP peers and servers must support EAP-TLS fragmentation. When performing EAP-TLS fragmentation, ZIP nodes must ensure that the maximum size of TLS data in a single EAP packet does not exceed EAP_TLS_MTU octets. However, ZIP nodes must still be capable of receiving EAP packets up to the maximum MTU size as they may originate from outside the ZigBee IP network.

6.2.9. TLS

Transport Layer Security version 1.2 (TLS) is used in conjunction with PANA, EAP, and EAP-TLS to provide authentication between a joining node and the Authentication Server. This section clarifies the definitions of constraints and specifications above and beyond those specified in [TLS].

6.2.9.1. TLS cipher suites

6.2.9.1.1. TLS-PSK cipher suite

As defined in [TLS-CCM], the PSK cipher suite must be TLS_PSK_WITH_AES_128_CCM_8.

6.2.9.1.1.1. Generation of the master secret from the PSK pre-master secret

[TLS-PSK] specifies the generation of the master secret from the pre-master secret. This section specifies the specific generation for the PSK cipher suite used.

```
master_secret = PRF(pre_master_secret, "master secret", ClientHello.random +
ServerHello.random);
```

The string "master secret" must not be null-terminated, that is, it shall be a length of 13 octets.

The PRF function must be iterated twice as the `master_secret` length is 48 octets and the hash output from SHA-256 is only 32 octets.

6.2.9.1.2. TLS-ECC cipher suite

As defined in [TLS-ECC-CCM], the ECC cipher suite must be TLS_ECDHE_ECDSA_WITH_AES_128_CCM_8.

As defined in [ECDP], the only elliptic curve to be used with this cipher suite must be the secp256r1 curve (also known as the NIST-P256 curve).

The hash algorithm to be used with this cipher suite must be SHA-256.

6.2.9.2. TLS key expansion from the master secret

[TLS] specifies the key expansion for generation of keying and IV material. This section defines the specific expansion for the cipher suites used and the use of the outputs.

```
key_block = PRF(master_secret, "key expansion", ServerHello.random +
ClientHello.random);
```

The string "key expansion" must not be null-terminated, that is, it shall be a length of 13 octets.

The PRF function must be iterated twice as the key_block length is 40 octets and the hash output from SHA-256 is only 32 octets.

- The `client_write_MAC_key` and `server_write_MAC_key` lengths are 0 due to the use of AEAD cipher.
- The `client_write_key` and `server_write_key` lengths are 16 octets. (SecurityParameters `enc_key_length` for [TLS-CCM] and [TLS-ECC-CCM])
- The `client_write_IV` and `server_write_IV` lengths are 4 octets. (SecurityParameters `fixed_iv_length` for [TLS-CCM] and [TLS-ECC-CCM])
- A total of 40 octets shall be required for keying material as follows:

    o `client_write_key` must be `key_block[0:15]`.

    o `server_write_key` must be `key_block[16:31]`.

    o `client_write_IV` must be `key_block[32:35]`.

    o `server_write_IV` must be `key_block[36:39]`.

6.2.9.2.1. CCM inputs

Only one CCM-protected record in the TLS sequence is used. This section defines the inputs for the AEAD cipher defined in [AEAD] Section 2.1.

6.2.9.2.1.1. CCM key input

The key used in the TLS sequence is `client_write_key` or `server_write_key`, depending on whether the client or server is encrypting.

6.2.9.2.1.2. CCM nonce input

The nonce is 12 octets long, as specified in [AEAD], and must be as follows.

Table 6-4: CCM nonce input values

Field	Octets	Value	Comment
IV data	0:3	-	Client IV or server IV depending on which is encrypting
Explicit nonce	4:11	{0,0,0,0,0,0,0,0}	Sequence counter for Finished handshake

6.2.9.2.1.3. CCM payload input

The payload must be the TLS record including the header.

6.2.9.2.1.4. CCM associated data input

The associated data ('A') must be 13 octets long as follows.

Table 6-5: CCM associated data input values

Field	Octets	Value	Comment
Explicit nonce	0:7	{0,0,0,0,0,0,0,0}	Sequence counter for Finished handshake
TLS record type	8	22	TLS handshake identifier
TLS Protocol Major	9	3	TLS 1.2
TLS Protocol Minor	10	3	TLS 1.2
TLS length MSB	11	-	Length of TLS record MSB
TLS length LSB	12	-	Length of TLS record LSB

6.2.9.2.1.5. Data link layer security

The data link layer security material is derived by each node from the network security material (see Section 6.2.6.2) received through PANA authentication or PANA key update process as described below.

The MAC key for the data link layer is set to the 16 higher octets of the result of:

```
HMAC-SHA256(Network Key,"ZigBeeIP")
```

The `Key Index` is set to the key sequence number.

The initial value of `Outgoing frame counter` is set to the following:

```
Node Auth counter || 00 00 00
```

where `||` is the concatenation operator and Node Auth counter is in the most significant octet position. The value of this field must be incremented by one each time the associated key is used to secure a message.

The data link layer security material is used to create a KeyDescriptor entry in the MAC key table described below. If the MAC key table is full, an existing entry, which is not the current active key, must be deleted to store the new KeyDescriptor entry.

Each ZIP node must maintain an attribute containing the key index of the current active MAC key.

When the first MAC KeyDescriptor entry is created, the active key index is set to the value of its key index. The active key index is updated subsequently through the network keys update mechanism (see Section 0).

The IEEE address-based EUI-64 MAC address of the originator, active MAC key, and active MAC key index must be used to secure outgoing data link layer data packets.

The procedures specified in the section related to data link layer security in [802.15.4] (Section 7.5.8 Frame Security of IEEE 802.15.4-2006) must be followed for applying data link layer security. The following sections indicate the mode of operation applied to data link layer security.

Note that the data link layer security attribute data described in the subsequent sections reflects the functional specification in [802.15.4]. The organization of the data is not optimized for storage space and does not imply any particular method of implementation.

6.2.9.2.2. Default key source

A participating node (one which has joined and has been authenticated and authorized) must have the following

configuration.

Table 6-6: Participating node configuration

PIB attribute	Value	Comment
macDefaultKeySource	0xff00000000000000	Arbitrary value indicating the MAC key. There is no need to store the actual IEEE address of the originator of the network key, as this may not be known.

6.2.9.2.2.1. Use of key identifier mode 1

Key identifier mode 1 must be used in conjunction with a MAC key. This implies the use of *macDefaultKeySource*. For a global MAC key used in conjunction with a MAC key index, this often means the lookup data required to be stored for identifying the MAC key reduces to the MAC key index only as there is no need to store the value of *macDefaultKeySource* along with the network key index. This mechanism is used as a convenience to limit the number of key ID modes in [802.15.4].

6.2.9.3. MAC key table

Note that [802.15.4] separates key storage from device descriptor storage and uses handles in key storage to point to the relevant device descriptors.

A participating node should have the following configuration. There are one active MAC key and (MAX_NWK_KEYS - 1) backup MAC keys.

Table 6-7: Participating node key table

PIB attribute	Value	Comment
macKeyTable	KeyDescriptor entries	One entry for the active MAC key, additional entries for backup MAC keys
macKeyTableEntries	MAC_MAX_NWK_KEYS	One entry for the active MAC key, additional entries for backup MAC keys

A ZIP node should have the following KeyDescriptor entry set for each MAC key.

Table 6-8: Key descriptors

KeyDescriptor attribute	Value	Comment
KeyIdLookupList	One KeyIdLookupList entry	Entry for this MAC key
KeyIdLookupListEntries	1	One entry for this MAC key
KeyDeviceList	KeyDeviceList entries	Entries in the MAC device table
KeyDeviceListEntries	(variable)	Number of entries in the MAC device table
KeyUsageList	KeyUsageList entries	One key usage for MAC data frames
KeyUsageListEntries	1	One key usage for MAC data frames
Key	(variable)	MAC key value

The KeyIdLookupList entry should have the following set.

Table 6-9: KeyID lookup descriptors

KeyIdLookupDescriptor attribute	Value	Comment
LookupData	*macDefaultKeySource* || KeyIndex	Only the KeyID needs to be stored. KeyIndex is the MAC key index associated with this MAC key.
LookupDataSize	0x01	Size: 9 octets

A KeyDeviceList entry points to a device descriptor. Each KeyDeviceList entry should have the following set.

Table 6-10: KeyDeviceList entry

KeyDeviceDescriptor attribute	Value	Comment
DeviceDescriptorHandle	Implementation-specific	Pointer to the appropriate device descriptor
UniqueDevice	0	The key is not unique per node.
Blacklisted	Boolean	Initially set to FALSE.

ZIP nodes should have one KeyUsageList entry that indicates that the MAC key is valid to be used for data link

layer data frames. Due to a static policy, this data can be implied and no storage is needed. The entry for data link layer data frames must have the following set.

Table 6-11: KeyUsageList entry for MAC data frames

KeyUsageDescriptor attribute	Value	Comment
FrameType	0x02	Data link layer data frame

6.2.9.4. MAC device table

A ZIP node should have the following set.

There is one DeviceDescriptor entry for each neighbor node this node is in communication with.

A ZIP router should be capable of having at least MAC_MIN_DEV_TBL entries in the MAC device table.

Table 6-12: MAC device table entry

PIB attribute	Value	Comment
macDeviceTable	DeviceDescriptor entries	One entry for each neighbor node this node is in communication with
macDeviceTableEntries	(variable)	One for each neighbor node this node is in communication with

The DeviceDescriptor entry for each neighbor node contains the following information.

Table 6-13: Participating node DeviceDescriptor entry

DeviceDescriptor attribute	Value	Comment
PANId	2 bytes	PAN ID of the neighbor node. Note this data can be implied and no storage is needed as the neighbor node will have the same PAN ID as this node.
ShortAddress	2 bytes	Short address allocated to the neighbor node
ExtAddress	8 bytes	IEEE address of the neighbor node
FrameCounter	4 bytes	Incoming frame counter of the most recently received MAC frame from the neighbor node
Exempt	FALSE	Exempt flag irrelevant as no security policy at the data link layer is in place, therefore this data can be implied and no storage is needed.

Note that [802.15.4] allows each of the KeyDecriptors to have a separate KeyDeviceList (list of DeviceDescriptors). This indicates that the neighbor nodes are eligible to use the particular key. A ZIP node consists of all entries in the MAC device table. It must maintain the same DeviceDescriptor list as the KeyDeviceList for each of its

KeyDescriptors. This implies that each key is valid to be used with any of the neighbor nodes.

6.2.9.5. Security level table

There is no security policy at the data link layer. The Enforcement Point performs policing based on the specification in Section 6.3.9.4. Therefore, all ZIP nodes must have the following set.

Table 6-14: Security level table

PIB attribute	Value	Comment
macSecurityLevelTable	Empty	No security policy at the data link layer
macSecurityLevelTableEntries	0	No security policy at the data link layer

6.2.9.6. Auxiliary Security header format

The MAC frame Auxiliary Security header (see Section 7.6.2 of [802.15.4] IEEE 802.15.4-2006) is used when a MAC frame is secured to provide additional data required for security.

6.2.9.6.1. Security Control field

The Security Control field must have the following values.

Table 6-15: Security Control field

Field	Value	Comment
Security Level	0x05	ENC-MIC-32 is the default value for ZigBee IP link-layer security.
Key Identifier Mode	0x01	The key is determined from the 1-octet Key Index subfield of the Key Identifier field of the Auxiliary Security header in conjunction with macDefaultKeySource.

6.2.9.6.2. Frame Counter field

The Frame Counter field must assume the value of the macFrameCounter PIB attribute.

6.2.9.6.3. Key Identifier field

The Key Identifier must be the MAC key index associated with the active MAC key.

6.2.10. MLE

The mesh link establishment protocol [MLE] provides a mechanism for nodes in a mesh network to exchange link properties with their neighbor nodes using the UDP protocol. In addition, it is used to propagate link configuration information to all nodes in the ZigBee network.

All ZigBee IP nodes must implement the MLE protocol.

6.2.10.1. MLE link configuration

All ZIP nodes must support the transmission and reception of MLE configuration messages. This includes the Link Request, Link Accept, Link Accept and Request, Link Reject messages. These messages are used to exchange the IEEE 802.15.4 interface properties and authenticate the frame counter value used by a neighbor node. These messages may include the following TLV options in the payload:

- The source address (TLV type = 0) TLV is used by a node to communicate its 16-bit short address and 64-bit IEEE 802.15.4 EUI-64 address.

- The mode (TLV type = 1) TLV is used by a node to communicate the node capability information. The Value field must be 1 octet in length and formatted as shown below.

Table 6-16: MLE link configuration format

bits: 0	1	2	3	4 - 7
Reserved	FFD	Reserved	RxOnIdle	Reserved

The FFD bit must be set to "1" by all nodes that are not a ZIP host. The RxOnIdle bit must be set to "1" by all nodes that have the radio enabled continuously (that is, non-sleepy nodes). The reserved bits must be set to "0" on transmission and ignored on reception.

- The timeout (TLV type = 2) TLV is used by a sleepy host node to communicate the period of inactivity after which the host can determine that communication with its parent node is disabled. A sleepy host node should perform periodic MAC polls with period lower than this value.

- The challenge (TLV type = 3) and response (type = 4) TLVs are used by a pair of nodes to authenticate each other's MAC frame counter values. The Value field in the challenge TLV must be set to a random value that is 8 octets long.

- The replay counter (TLV type = 5) TLV is used to communicate the value of the MAC outgoing frame counter.

6.2.10.2. MLE advertisement

All ZIP routers must support the transmission and reception of the MLE Advertisement messages. This message is used to exchange bidirectional link quality with neighbor routers. The bidirectional link quality is used to improve the quality of the RPL parent selection. In addition, this message is used to detect changes in the set of neighbor routers.

A ZIP router that has joined the network must periodically transmit the MLE Advertisement message every MLE_ADV_INTERVAL.

The MLE Advertisement message must contain the link quality (TLV type = 6) TLV in its payload. The neighbor records in this TLV must contain information about the nodes in the MAC device table of the originating node. The Neighbor Address field in each of the neighbor records must be contain the 16-bit short address of the particular neighbor node. The P (priority) flag should be set for neighbor nodes that are part of the RPL parent set. This is to give an indication to those neighbor nodes that they should prioritize maintenance of link with this node.

A ZIP router must remove the MAC device table entry corresponding to a neighbor router if it did not receive an MLE Advertisement message from that neighbor router containing a neighbor record for itself in MLE_ADV_TIMEOUT.

6.2.10.3. MLE update

The ZIP coordinator must support origination of MLE Update messages. All ZIP nodes must support the reception of the MLE Update messages.

The MLE Update message is used by the ZIP coordinator to configure the values of various link layer parameters in the network. The MLE Update message must contain only one instance of the network parameter TLV. This TLV must contain one of the following parameters:

- The Channel network parameter is used to configure the channel that must be used by the node. It must contain a 2-octet-long Value field. The higher-order octet of the Value field contains the channel page number and the lower-order octet contains the channel number. The definition of the channel pages and channel numbers for each physical layer is in [802.15.4].

- The PAN ID network parameter is used to configure the 802.15.4 PANID value that is used by the nodes in the network. It must contain a 2-octet-long Value field that contains the new PANID. A receiving node must use this value to update the corresponding attribute in the data link layer. In addition, it must update the corresponding field in each of the MAC device descriptor entries. (See **Table 6-13**.)

- The Permit Joining network parameter is used to configure the Allow Join field that should be used by the node. (See Section 6.3.3.1.) It must contain a 1-octet-long Value field. A ZIP router must use the value of the lowest significant bit in this octet to set the value of the Allow Join parameter in its beacon payload. The other bits in the Value field must be set to zero on transmission and ignored on reception.

- The Beacon Payload network parameter is used to configure the Optional field in the beacon payload (see Section 6.3.3.1). The receiving node replaces all Optional fields in its current beacon payload (see **Table 6-18**) with the contents of the Value field in this message. Since only a single parameter TLV can be included in an MLE Update message, the ZIP coordinator must ensure that it includes the complete concatenated set of all the Optional fields in a single TLV. Note that this can also be a zero length value if no Optional fields are to be included in the beacon payload.

The network parameter TLV format contains a Delay field that is used to specify the delay value before the receiving node takes action to configure the appropriate parameter. When the parameter is either Channel or PanID, the Delay field should be larger than the time it takes for the multicast packet propagation in the network. This is to ensure that all nodes receive the MLE Update packet before any of them change their parameter. The recommended value is 5 seconds.

ZIP nodes may ignore a new MLE Update message with a network parameter TLV if a previous message with the same TLV has not yet been acted upon. The ZIP coordinator should ensure that successive MLE Update messages with the network parameter have sufficient delay between them to avoid this scenario.

In rare situations, a ZIP node may become stranded if the MLE Update message with Channel or PanID is not received correctly by all nodes. The detection of this state on each node is out of scope of this specification. The recovery procedure is to perform network discovery on all channels to find the network and then attempt network rejoining.

MLE Update messages must be transmitted to the subnet-local all-routers multicast address.

6.2.10.4. MLE message security

MLE messages may sometimes be exchanged before a node has joined the network and configured secure links with its neighbor nodes. Therefore, MLE messages cannot always rely on data link layer security and the MLE protocol defines its own mechanism to secure its payload.

MLE configuration messages should be secured at the MLE layer and unsecured at the data link layer. An MLE configuration message without any security can be exchanged only during the initial phase of the node bootstrapping process when the new node has not yet acquired the security material. Subsequently, a node must always apply security to MLE configuration messages. A ZIP node must ensure that an incoming MLE configuration message that does not have MLE security does not change any state information for existing node entries. The transmitter must use its LL64 IP address as the source address for these packets.

MLE Advertisement messages must be secured at the MLE layer and should be unsecured at the data link layer and transmitted. The transmitter must use its LL64 IP address as the source address for these packets. An incoming MLE Advertisement packet that does not have MLE security must be discarded. A node should verify the freshness of MLE Advertisement messages from nodes with which it has configured a secure link.

MLE Update messages should not be secured at the MLE layer and must be secured at the data link layer. These messages are only transmitted to nodes that are already part of the network, so it is possible to apply data link layer security. In addition, since MLE Update messages are transmitted to a site-local multicast address, it must use MAC security or the packets would not be forwarded by the other ZIP nodes (see Section 6.3.9.4). Also, it is not possible to use MLE security for these packets as the transmitting and receiving nodes may not have a secure link configured with each other unless they are in direct radio range.

6.2.10.5. MLE security material

The MLE security material used for securing MLE packets contains the following parameters.

Table 6-17: MLE security material

Parameter	Size	Comment
MLE Key	16 octets	MLE key
Key Index	1 octet	Key index associated with this key
Outgoing frame counter	4 octets	Value of the frame counter used to secure outgoing MLE messages with this key

The MLE security material is derived by each node from the network security material (see Section 7.3.2) received through the PANA authentication or PANA key update process as described below:

The MLE Key is set to the 16 lower octets of the result of HMAC-SHA256 (Network Key, "ZigBeeIP").

The Key Index is set to the network key sequence number.

The initial value of the Outgoing frame counter is set to the following:

Node Auth counter | | 00 00 00

where | | is the concatenation operator and Node Auth counter is in the most significant octet position. The Node Auth counter value must be incremented by one each time the associated key is used to secure a message.

A ZIP node must store the MLE security material derived from the two most recent network security materials that originated from the Authentication Server. These are designated as active and alternate MLE security materials.

When a new security material is received originating from the Authentication Server, it must be stored in the active location if that is empty. Otherwise (if a security material has already been stored), it must be stored in the alternate location.

Security for outgoing MLE packets must be applied by using the active MLE security material. Security for incoming MLE packets must be applied by using the MLE security material with the index that matches the index contained in the MLE Auxiliary Security header of the incoming message.

The Security Control field in the MLE message auxiliary header must use the same values as used for data link layer security. The security level must be 5 (CCM encryption with 4-octet MAC address) and the key identifier mode must be 1. The address used for the CCM nonce must be the 64-bit MAC address for the node. The frame counter must be the MLE outgoing frame counter.

6.3. Functional description

6.3.1. Overview

A ZigBee IP network consists of a single ZIP coordinator node and multiple ZIP router and ZIP host nodes. These nodes form a single PAN from an IEEE 802.15.4 perspective. From an IPv6 perspective, they form a single multilink subnet with a common prefix.

A ZigBee IP network is formed by the ZIP coordinator when it starts operation as an IEEE 802.15.4 PAN coordinator and configures its IEEE 802.15.4 interface as an IPv6 router.

Once the network is created, other nodes can join the network as either ZIP routers or ZIP hosts, depending on their capabilities.

A new node can join the network through a three-step process of network discovery, network admission, and network authentication that are detailed in later sections (Sections 6.3.3, 6.3.4, 6.3.5, and 6.3.6). Once a node has joined the network, it may allow other nodes to join through it if it is a ZIP router. This allows the formation of a wireless mesh network that extends beyond the radio range of the ZIP coordinator.

Nodes that are part of a ZigBee IP network share a unique network key that is used to derive other encryption keys which are then used to secure all packets at the link layer. A node acquires this key during the initial join process and it may be updated over time.

6.3.2. Network formation

6.3.2.1. Data link layer configurations

A node that is administratively configured to form a new IEEE 802.15.4 PAN network will perform the following steps:

- The node conducts a MAC energy detect scan on all preconfigured channels and identifies channels with energy level below a configured threshold. The list of channels to scan is administratively configured.
- The node conducts a MAC active scan using the standard beacon request on the channels selected in the previous step.
- The node then selects a channel with the smallest number of existing IEEE 802.15.4 networks.

- The node chooses a PANID that does not conflict with any networks discovered in the previous steps and also configures a randomly generated 16-bit short address.
- The node starts an IEEE 802.15.4 PAN on the selected channel and PANID.

6.3.2.2. IP configurations

Upon starting a new PAN, the ZIP coordinator shall prepare to configure the 6LoWPAN with 64-bit IPv6 global prefix(es) (if any) that are either globally unique or ULA [RFC 4193]. The prefix(es) may be configured administratively or acquired from an upstream network via DHCPv6 prefix delegation or other means that are out of scope of this standard.

After the 6LoWPAN IPv6 prefix(es) have been configured, the ZIP coordinator configures its IEEE 802.15.4 interface with IPv6 address(es) composed of the 6LoWPAN prefix(es) and the interface identifier created from the node 16-bit MAC short address.

The ZIP coordinator may have other interfaces besides of the IEEE 802.15.4 interface and the initialization of those interfaces is out of scope of this specification.

Once the IPv6 configuration is completed, the ZIP coordinator participates in Neighbor Discovery (ND) protocol exchanges according to [6LPND]. The ZIP coordinator configures the default context identifier as the /64 prefix assigned for the use throughout the 6LoWPAN. The ZIP coordinator may maintain other context identifiers up to a maximum of MIN_6LP_CID_COUNT, including the default context identifier. As defined in [6LPND], the ZIP coordinator uses multihop prefix and context distribution.

The ZIP coordinator initiates a new RPL instance and forms a DODAG with the operational parameters from Section 5.5.4.2.3. As additional nodes join the network, the ZIP coordinator begins participating in RPL protocol exchanges according to [RPL].

The ZIP coordinator initializes the PANA authentication service. The network security material (see Section 6.2.6.2) is generated with a random 128-bit network key and a key sequence number of 1. The data link layer and MLE layers begin to use key material derived from the network security material. In addition, the Authentication Server configures the network security material disseminated through the ZigBee vendor specific Network Key AVP (see Section 6.2.6.3).

6.3.3. Network discovery

The network discovery procedure is used to discover other IEEE 802.15.4 networks that are within radio propagating range. For each network, the network ID along with some associated information is discovered in this process.

ZigBee IP nodes perform network discovery using the MAC beacon functionality.

All ZigBee IP nodes must be capable of transmitting the MAC beacon request command packet. The ZIP coordinator and all ZigBee IP routers must be capable of processing a beacon request command and transmitting a beacon packet in response.

To perform general network discovery, a ZigBee IP node transmits a beacon request packet and collects all responses. This is typically used by a node before starting a new network so that it can identify existing PANIDs and channels that are being used locally.

The network discovery process also allows a node to discover the router nodes that are in radio range. One of these routers is selected as a "parent" router for the purpose of joining the network.

6.3.3.1. Beacon payload

The MAC beacon command packet is transmitted in response to a beacon request packet. The beacon packet contains an application-configurable payload field that is used to convey information about the network. A ZigBee IP router must configure its beacon payload field as follows.

Table 6-18: Beacon payload format

Octets: 0	1	2 – 17	18 – variable
ZigBee protocol identifier	Control field	ZIP NetworkID	Optional fields

- octet Protocol ID – This field must be set to 0x02. It is used for ZigBee IP networks and helps to distinguish them from other IEEE 802.15.4-based networks that are located in radio propagation range.
- octet Control field – This field is used to convey information about a joining device. It can choose an appropriate network and parent router to join. It contains multiple subfields that are formatted as shown below.

Table 6-19: Beacon payload control field format

Bits: 0	1	2	3 – 7
Allow join	Router capacity	Host capacity	Reserved

  - The Allow Join bit provides a hint to new joining nodes if this network is currently allowing new nodes to join the network. It is set to 1 to indicate that this network is currently allowing new device joins. The value of this field is propagated through the network using upper layer protocols (see Section 6.2.10.3) and configured by the node management application on the ZIP coordinator. When a ZIP router initially joins the network, it sets the value of this field to the same value that was used by its parent router. Subsequently, the value of this field is configured based on a new incoming MLE Update message received from the ZIP coordinator. In order to protect against loss of an MLE Update message, a ZIP router must automatically set this field to 0 if it has been set to one for a time longer than MLE_MAX_ALLOW_JOIN_TIME.

  - The Router capacity and Host capacity bits are used to indicate whether the source of the beacon packet has the capacity to accept a new host or router node to join the network through it. The values of these bits are set by the management entity on each node depending on its resource availability (for example, depending on availability of space in neighbor cache and MAC device table).

  - The reserved bits must be set to zero on transmission and ignored on reception.

- NetworkID – This 16-octet field, interpreted as ASCII characters, is used to identify a specific network to a user. The value of this field is administratively configured and managed by the ZIP coordinator. Other ZIP routers receive the value of this field from the beacon payload of the parent router via the network.
- Variable-length optional fields may be included in the beacon payload using the type-length-value format. Each

optional fields is formatted as shown below.

Table 6-20: Beacon payload optional field format

Octets: 1		2 - Length
Bits: 0 - 3	4 - 7	
Length	Type	Value

- The Type subfield is 4 bits long and identifies the type of field. The following values are defined.

Table 6-21: Beacon payload optional field types

Type	Description
0	4-octet value that is used as a node identifier to steer a specific node to join the network. For example, this can be set to the truncated hash of the device certificate.
1 - 15	Reserved

- The Length subfield is 4 bits long and identifies the length of the Value subfields in octets.

- The Value subfield contains the value of the field.

A node must ignore any optional fields that it does not support and continues to process the others.

6.3.4. Network selection

The discovery procedure can result in discovery of multiple ZigBee IP networks in radio propagation range. The selection of the network that a node must attempt to join is done via application-specific means. The ZigBee IP specification provides various tools that can be used by a joining node to join the correct network that it must join. Some of these tools are described further below in this section.

- "Allow Join" flag indication - This flag is present in the beacon payload of all ZigBeeIP routers. A joining node can examine this flag for all neighbor ZigBee IP routers to select an appropriate network. The routers in a network would normally set this flag to zero. When a new node is expected to join the network (as determined by application-specific means), this flag would be set to true (1) for a specific period. The ZIP coordinator is responsible for propagating the value to be used in field to all routers in the network.

  Note that this parameter is only a hint to the joining nodes. The behavior of a ZIP router does not change based on the value of this field. Specifically, if a ZIP router has this flag set to zero, it must still continue to allow new nodes to join through it. Only the ZIP coordinator may reject the join attempt.

- "User selection" - The joining node would perform a beacon scan and discover all ZigBee IP networks in its radio range. It would then display information about the networks and allow a user to select the network it should join.

- "Preconfigured information" - The joining node could update the configuration with information about the specific network it must join. This information could be, for example, the "NetworkID" field in the beacon payload.

- "Device identifier" - The identifier of the joining node is included in the beacon payload. This method can be used if the identity of the joining node is known to the ZIP coordinator, so that it can propagate this information to all the routers in the network for inclusion in the beacon payload.

Note that this is not an exhaustive list and an application may implement other means for selecting the network to join. Additionally, it should be noted that these mechanisms only provide "hints" to the joining node to aid in network selection. It is expected that after selecting a network and joining it, the node would use an application level registration mechanism to validate that it has joined the correct network. If the node fails application validation, the management entity should blacklist that network and repeat the network selection and joining process.

6.3.5. Node joining

After network discovery and selection, the joining node performs the bootstrap procedure to gain access to the network. The typical joining sequence is shown in the figures below and detailed in the following subsections.

6.3.5.1. Host bootstrapping

The ZigBeeIP host node bootstrapping sequence is described below.

1. The node performs network discovery, uses the selection procedure as described previously, and selects an appropriate network to join.

2. A parent router is chosen from among the ZIP routers that belong to the selected network. This is usually the router that has available host capacity (Host capacity subfield in the beacon payload is set to 1), and whose beacon was received with the best LQI (link quality indicator).

3. The node configures its IEEE 802.15.4 MAC PAN identifier (PAN-ID) to that of the selected target network.

4. The node configures an IPv6 link local address for its IEEE 802.15.4 interface using the LL64 address format.

5. .If the node is a sleepy host, it must use the MLE protocol exchange to inform the parent router that it is a sleepy device and will use the MAC polling feature for layer-2 packet transmission. This information is included in the mode TLV option of the MLE link request packet.

   The parent router configures MAC polling for node's EUI-64 address. If the parent router has no capacity to accept a sleepy node, it must reject the link request and the joining node should then select another parent router and continue from Step 2 of this process.

   If the node is a sleepy host, it must perform the MAC polling using its EUI-64 address until it has configured a unique short address and registered it with its parent router using the MLE protocol. (See Step 11 in this sequence.)

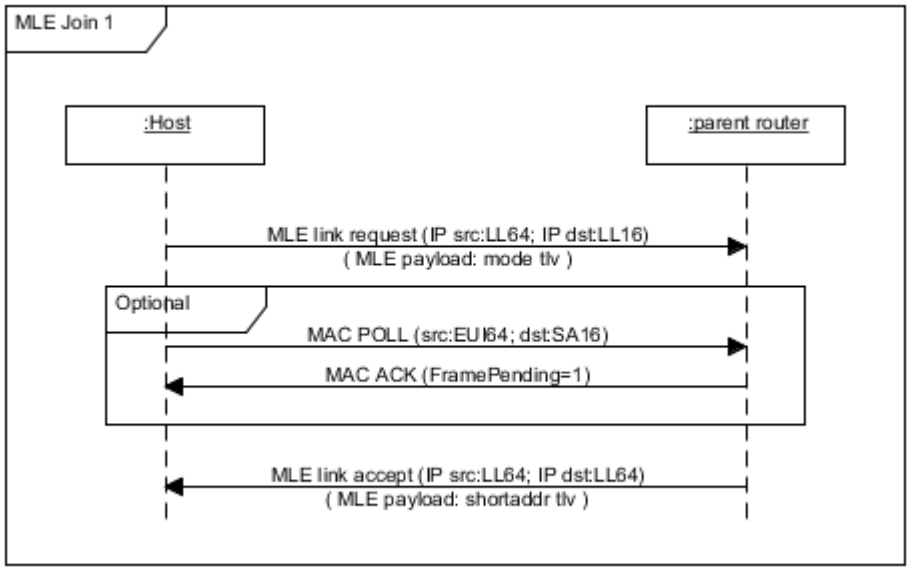


Figure 6-2: Join sequence - MLE 1

6. The node performs network authentication using the PANA protocol. Upon successful completion of this procedure, the node is admitted into the network and acquires the network security material. See Section 6.5.3.4 for an example message sequence.

7. The node performs a 3-way secured MLE handshake to synchronize frame counters with the parent router. At the end of this procedure, the node knows the frame counter of the parent router and the parent router knows the frame counter of the node.

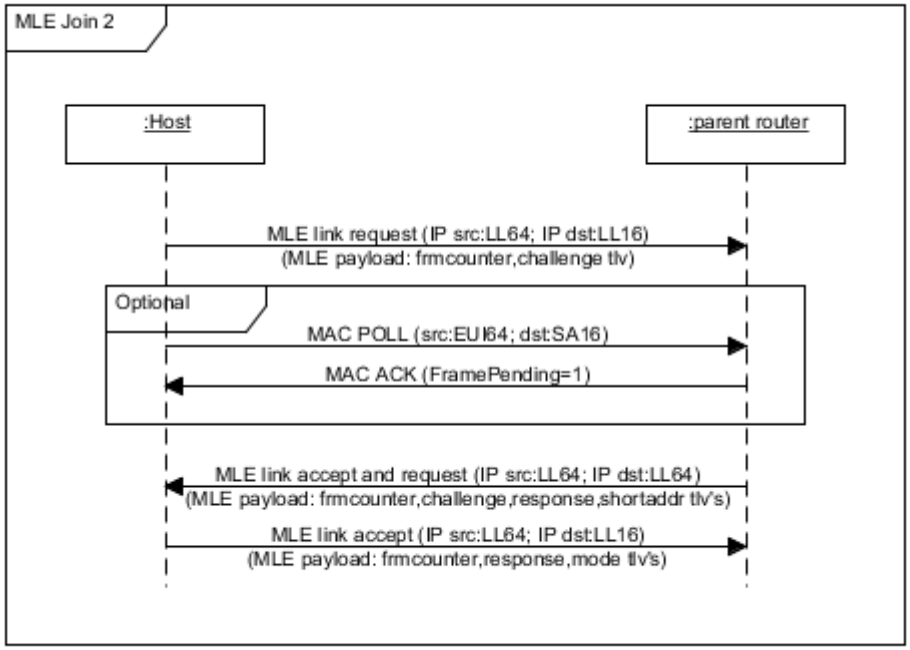


Figure 6-3: Join sequence - MLE 2

8. The node performs IPv6 router discovery described in [6LPND] by transmitting a Router Solicitation packet and waiting for Router Advertisement in response. The IPv6 prefix that is in use in the ZigBee IP network is extracted from the PIO option of the received Router Advertisement packets.

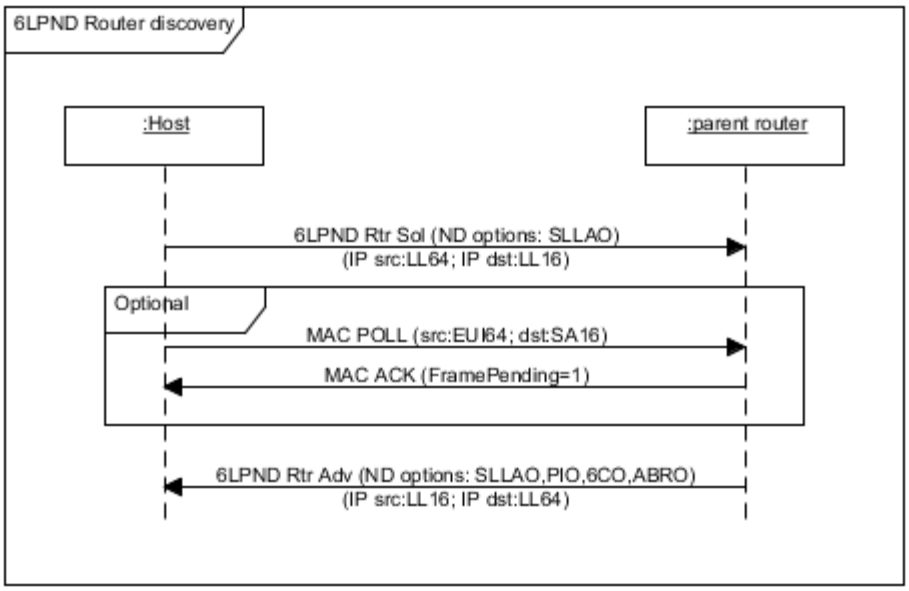


Figure 6-4: Join sequence - Router discovery

9. The node configures a randomly generated 16-bit address as its MAC short address. This address must not take the value 0xFFFE or 0xFFFF in accordance with the [802.15.4] specification. The node then configures an IPv6 global unicast address (GP16) and an IPv6 link local address (LL16) using the IID formed from this 16-bit MAC short address.

10. The node performs DAD (duplicate address detection) procedure for the global unicast address as described in [6LPND]. The parent router uses the DAR/DAC packets to register the GP16 address with the ZIP coordinator and check for uniqueness. Note that this also implies that the 16-bit MAC short address is unique within the ZigBee IP network. If the GP16 address is determined to be a duplicate, the node chooses a different GP16 address and repeats this process. Note that the node needs to use its IPv6 source address (as required in [6LPND]) and the GP16 address it is claiming during the 6LoWPAN neighbor discovery protocol exchange. The 16-bit MAC short address cannot be used until it has been confirmed as unique. Therefore, this message exchange contains use of mixed 64/16 addressing modes (that is, the IPv6 address is formed using the 16-bit MAC address as the IID, however, the MAC address used is the 64-bit address).

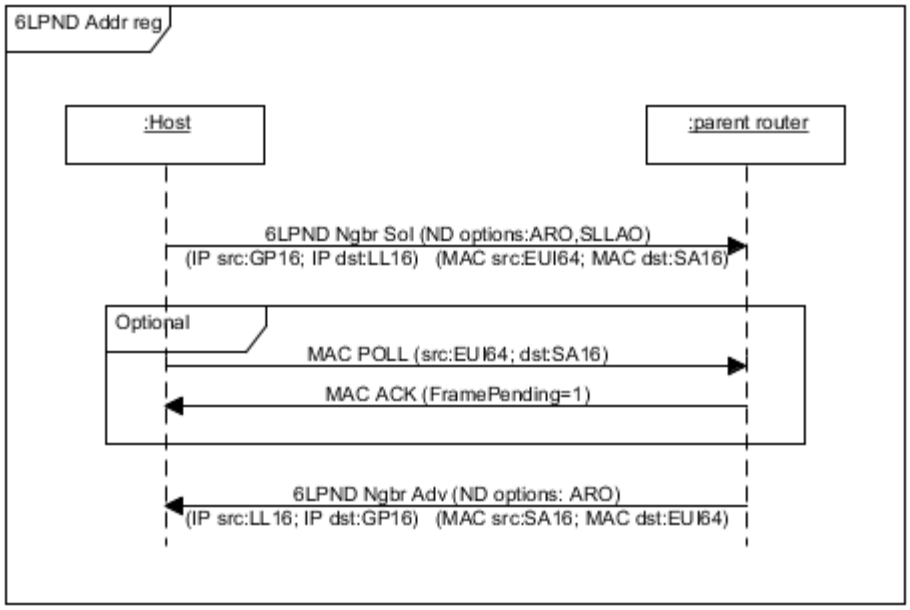


Figure 6-5: Join sequence - Address registration

11. The node performs a 3-way MLE handshake to exchange short addresses with the parent router. The node must include its unique 16-bit short address in the MLE payload in either the Link Request or Link Accept packet. At the end of this procedure, the node knows the short address of the parent router and the parent router knows the short address of the node. If the node is a sleepy host, it must begin to use its short address to perform MAC polling as soon as it has updated the parent node with its short address.

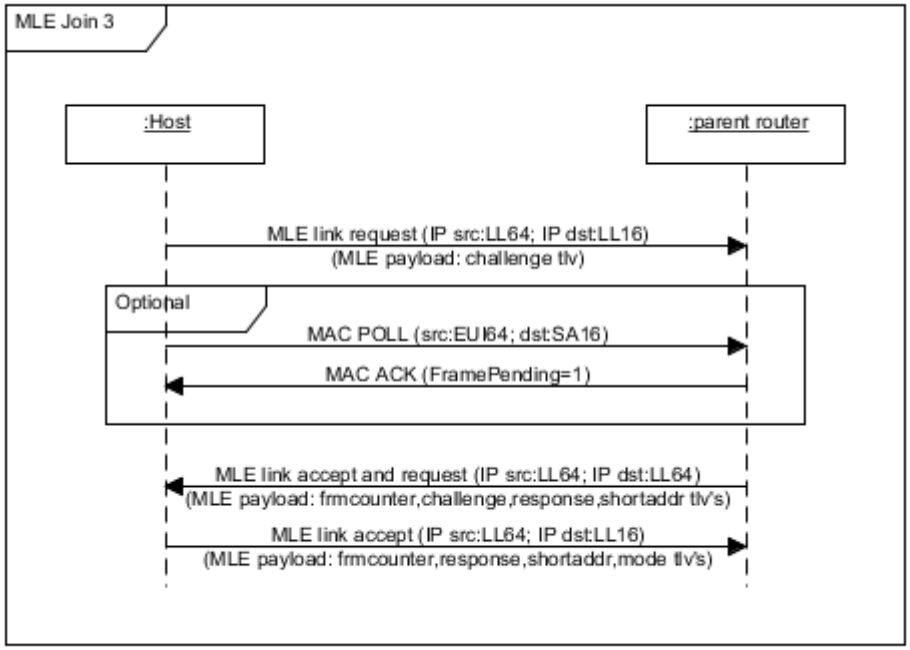
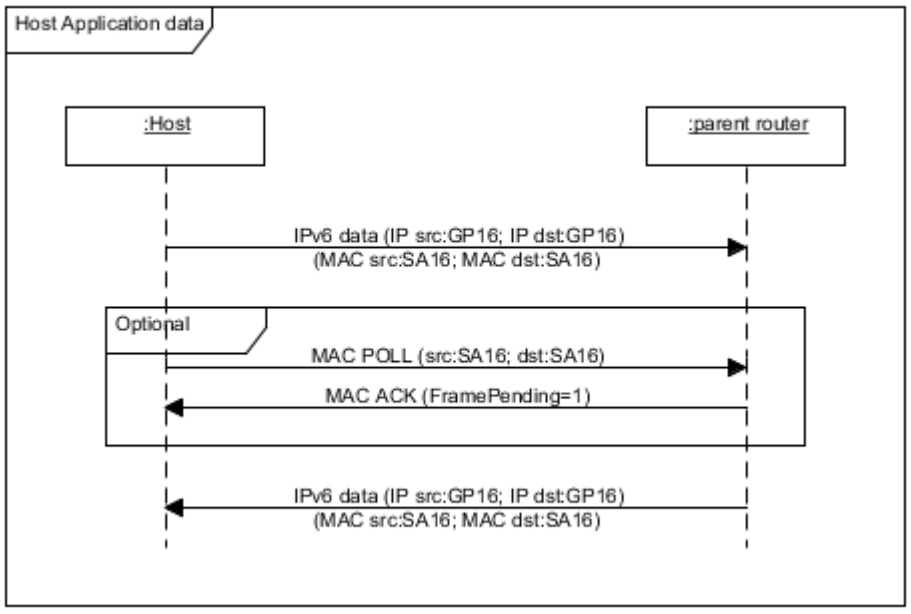


Figure 6-6: Join sequence - MLE 3

12. The parent router must check if the new node is a ZIP host. The mode TLV in the MLE message (see Section 6.2.10.1) should be used to make this determination. If the joining node is a host, the parent router must transmit RPL DAO messages to the DODAG root to create downward routes to the new node. The DAO message must contain the GP16 address of the joining node in the Target Prefix option and the GP16 address of the parent node in the Transit option. The External (E) flag must be set to 1.

This concludes bootstrapping for hosts. The host node can now transmit and receive IP packets through its parent router.



6.3.5.2. Router bootstrapping

The bootstrapping sequence for a ZIP router is described below.

1. The ZIP router follows the bootstrap sequence described for the host node with the following exceptions. The ZIP router must select its initial parent router from among those routers that have indicated available router capacity, which is indicated by setting the router capacity subfield in the beacon payload to 1. Since the ZIP router cannot be a sleepy node, the initial MLE exchange before PANA authentication (Step 5 in the host sequence) is optional. It follows the host sequence up until the final step (Step 11 in the host sequence) and then continues as follows.

2. The ZIP router discovers its neighbor ZIP router nodes and configures secure layer 2 links. This is accomplished using the MLE handshake exchange. The initial MLE Link Request packet is transmitted using the MAC broadcast address. All ZIP routers that are in radio range will receive this packet and may respond with an MLE Link Accept and MLE Link Request, depending on their available capacity to configure additional layer-2 links. (Note that the capacity to configure layer-2 links is limited by the size of the MAC device table.)

   The joining router selects a subset from the responding ZIP routers and completes the MLE link establishment process with each of them. The selection of this subset is out of scope of this specification.

This will cause the MAC device table in the joining router to be populated with entries for the selected neighbor routers. The joining router should ensure that it does not use up all of MAC device table capacity at this time. In order to allow other joining nodes to join the network later, it should ensure that it has some spare capacity in its MAC device table.

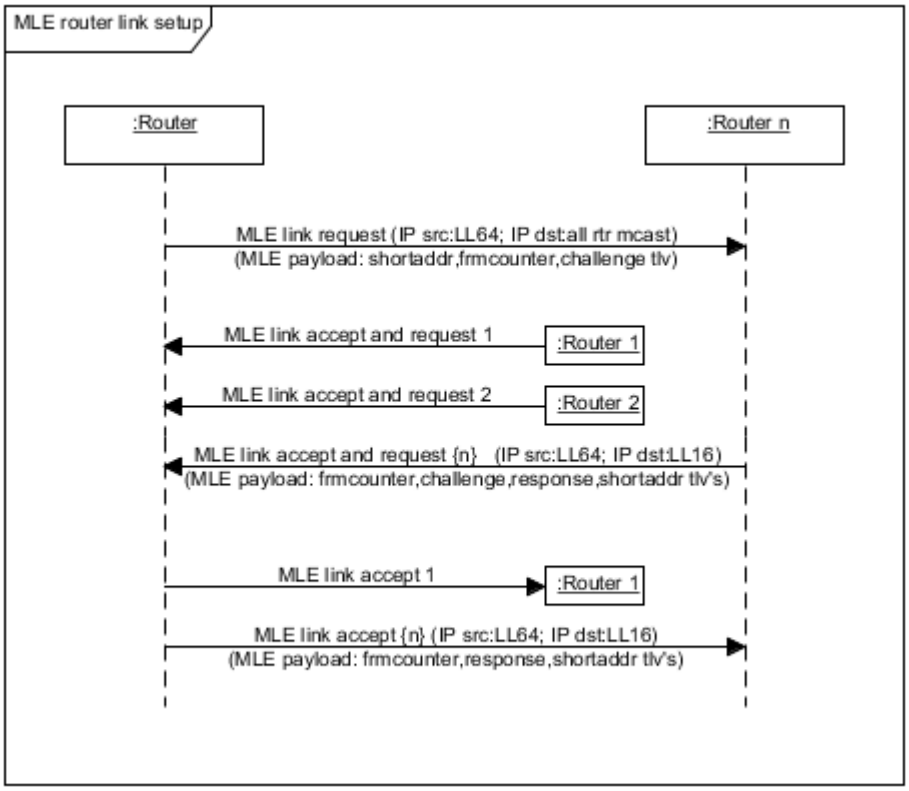


Figure 6-8: Join sequence - Router link setup

3. Next, the ZIP router begins configuration of the RPL routing protocol. The node transmits a multicast DIS packet to discover all available RPL instances. The node joins each RPL instance in turn using the sequence of messages below.

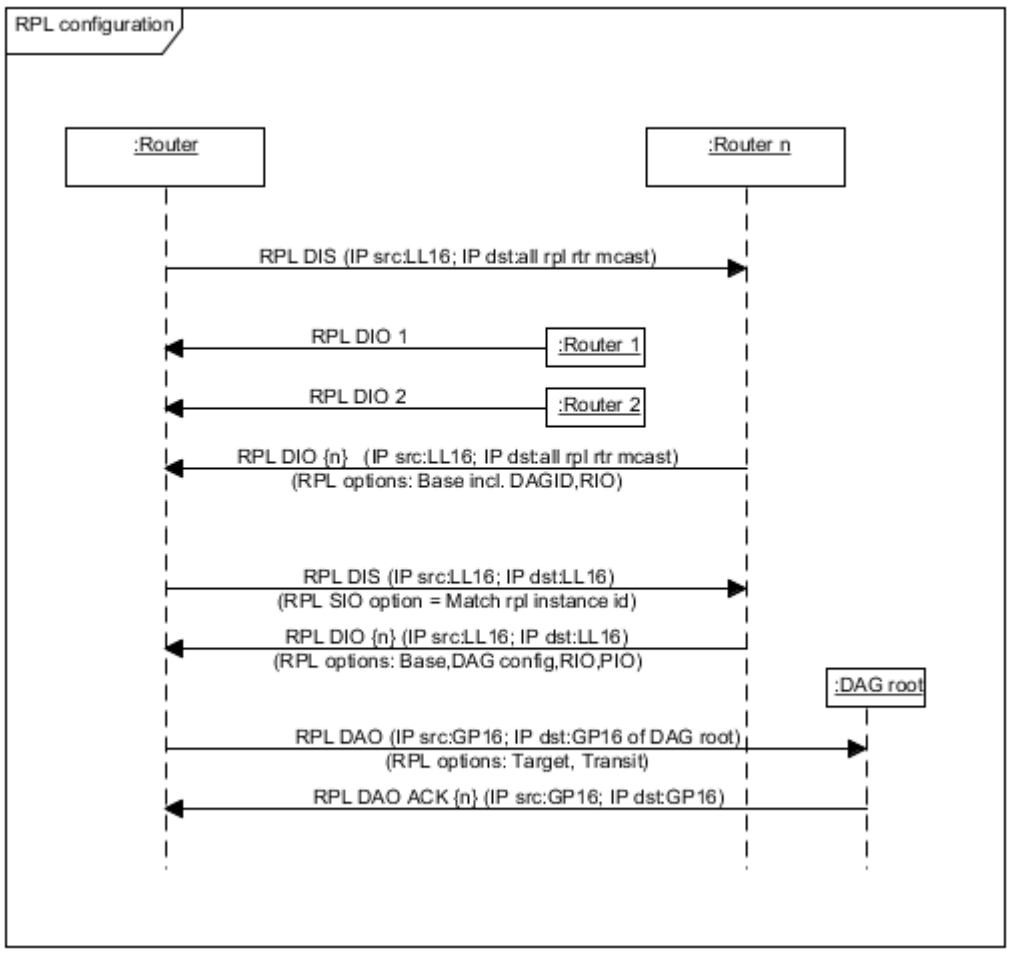


Figure 6-9: Join sequence - RPL configuration

4. The ZIP router is now part of the network and has full communication ability. The final step in the bootstrapping sequence is for the ZIP router to configure itself to function as an access router so that is can admit new nodes into the network. For this, it must configure the MAC beacon payload as described in Section 6.3.3.1 and must start the MAC coordinator service so that it can transmit beacon packets in response to incoming beacon request packets. The association permit flag in the beacons must be set to false. It must enable the PANA Relay service. It must begin periodic transmission of MLE Link Advertisement packets. It must update the PANA Authentication Server with its new GP16 address as described in Section 6.3.9.3.6.

6.3.6. Network admission

When a new node joins the ZigBee IP network, it uses the PANA protocol to authenticate itself to the ZIP coordinator and gain access to the MAC security material. Once a node is admitted into the network, it has full access to all communication capabilities on the network.

The Authentication Server can choose to eject an already admitted node from the network. It can do so by performing a selective update of the network key to all nodes except those that it has revoked access. The Authentication Server must perform the network key update twice in order to completely revoke network access for that node. See Section 6.3.10 for details on the updating network keys.

6.3.7. 6LoWPAN fragment reassembly

ZIP nodes must transmit 6LoWPAN fragments in order and must complete transmission of the current IP datagram before beginning transmission of another to the same next hop node. This allows a number of optimizations on the receiving node.

A ZIP node should buffer at most one incoming fragmented message from each neighbor node. When receiving a fragmented message from a neighbor, if a 6LoWPAN packet arrives from that neighbor that is not the excepted next fragment, the partial message may be discarded. Also, if a non-initial fragment arrives that is not the expected next fragment, both that received fragment and any partially received message may be discarded.

6.3.8. Sleepy node support

Hosts in a ZigBee IP network may be battery-operated and can operate their radio for only a small fraction of time. Such hosts are called sleepy hosts. A ZIP router is not allowed to be sleepy and must always have its radio enabled.

A sleepy host node receives data using the [indirect transmission scheme] using the data link layer defined in [802.15.4]. In this scheme, the transmitting node buffers the outgoing MAC packet. When the sleepy host activates its radio, it transmits a MAC POLL command packet to its parent router and then enables its receive function. The parent router transmits an acknowledgement packet in response to the MAC POLL command packet and indicates within that if it has any buffered packets to the sleepy node. The sleepy node would continue to keep reception enabled if it sees that the parent router has buffered packets for it. This allows the parent router to transmit the buffered packets to the sleepy host right after transmitting the acknowledgement packet.

ZIP routers must keep track to sleepy host nodes. The ZIP router acquires this information through the Mode Type option in the MLE message. The packet transmission to those nodes should use the MAC indirect scheme as defined in [802.15.4]. A ZIP router must have the ability to buffer at least MAC_MIN_INDIRECT_BUFFER full IPv6 packets. Each packet that is buffered for indirect transmission must be queued until successfully transmitted or for a period of at least MAC_MIN_INDIRECT_TIMEOUT. ZIP routers can prevent sleepy hosts from selecting them as the parent router by clearing the Host capacity bit in the MAC beacon payload. This should be done if a ZIP router has reached an internal limit on the number of sleepy host nodes it can service reliably.

Note that a sleepy host may change its sleepy nature dynamically. The sleepy host must update its status with the parent router every time it changes its sleepy status. This is done using the Mode type option in the MLE message. For example, if the application on the sleepy host is aware that a large amount of data is to be stored (as is the case if the node is receiving a new firmware update), the host may change its status to a non-sleepy host and receive the packets using direct data forwarding. This will reduce the strain on the parent router buffers and also make the data forwarding faster and more reliable.

It is expected that sleepy host devices are usually the initiator of application-level transactions. They should usually not receive unexpected packets. When a sleepy host node is expected to receive packets, it should be able to poll its parent router at a faster rate than usual so that it can improve the probability that the packet buffered by its parent router is received successfully.

Special measures are necessary to accommodate sleepy hosts in a ZigBee IP network. Measures described below allow a host to communicate using indirect transmission even during the joining process.

6.3.8.1. Sleepy host joining

The initial node bootstrapping process is described in Section 6.3.5.1 and the following text provides additional

details.

A sleepy node starts the joining process without a short MAC request. The source address used for data transmission at the MAC layer is initially the 64-bit MAC address of the joining host.

A sleepy host should indicate its sleepy nature to its parent router during the initial bootstrapping process. This is done through an MLE Link Request message (see Step 5 in Section 6.3.5.1). The Mode TLV is included in the Link Request message and the "Capability Information" field defined in [802.15.4] is contained as the value.

The parent router must respond with an MLE Link Accept or Reject message. The host must transmit the response to the joining host using MAC indirect transmission, as this allows the host to poll for it. A ZIP router must not accept a sleepy host as a child, unless it has the capability to buffer at least one IPv6 packet for a specified period of time, as a requirement of establishing a new link (space table in the MAC device, etc.). If a ZIP router does not have the necessary capacity to service a sleepy host node, it must transmit an MLE Link Reject message in response to the MLE link request.

Note:

Though the sleepy node confirms a unique short address in Step 10 (neighbor discovery) of the bootstrapping sequence described in Section 6.3.5.1, it must not configure the short address in the data link layer until the parent node updates information to new one during Step 11 of the bootstrapping sequence. The joining node is polled using the extended address until that time. The node must use its extended address for the MAC polling and then use its short address.

6.3.8.2. Polling rate

A host has two sleeping modes: DEEP and SHALLOW. For a sleepy host node, there are two types of sleeping modes: fast poll and slow poll. The difference between the two modes is the MAC polling rate.

During fast poll, a sleepy node should be polling its parent router with sufficient frequency in order to receive its packets in a reasonable period of time. The reasonable polling interval depends on the retransmission timers in the upper layers. For example, in TCP, the initial retransmission timeout is set at 3 seconds and increases with each successive retransmission. In order not to trigger unnecessary retransmissions, a host must poll its parent router at least once every MAC_MAX_FAST_POLL_TIME when it is in the fast poll state.

A sleepy host in the slow poll state can slow its polling rate significantly. A sleepy device may enter the slow poll state at any time. If a device wants to be able to enter the slow poll state, it must communicate this to the parent during the link establishment process, by including a Timeout TLV in the MLE exchange. The Timeout TLV indicates the maximum interval between successive polls (that is, polling period during the slow poll state). The value of the Timeout field must be MAC_MAX_POLL_TIME or less. Note that the requirement on the parent router to buffer the IP packets for at least MAC_MIN_INDIRECT_TIMEOUT does not change when the sleepy host is in the slow poll state. For this reason, there is very high chance that a sleepy host node will not be able to receive packets when it is in the slow poll state.

A sleepy node should be in the fast poll state if it expects to receive packets, and may enter the slow poll state otherwise. For example, it should be in the fast poll state when it has transmitted an MDNS or HTTP request and is waiting for the response.

The applications operating on ZIP nodes should be aware that sleepy host nodes are not always reachable as they may be in the slow poll state. It is typically safe to respond to queries (for example, MDNS or HTTP) that are initiated by a sleepy host as the node would be expected to be in the fast poll state for a reasonable duration after transmitting

the query.

6.3.8.3. Data link layer data request command frame security

MAC data request command frames unencrypted at the data link layer are always transmitted (that is, polls). More specifically, a parent must not discard unsecured polls from its children at the data link layer, even if there is a child with which a link has been established. The reason for this is that the child may be rejoining the network or performing key update after a key switch, and may not have the current network key. Since parents always accept unsecured polls, there is no reason for sleepy children to secure them, even if they have the network key.

6.3.8.4. Sleepy host node link maintenance

The network status may be changed when a node is in the Deep Sleep mode. For example, the network key may have been updated and the radio link with the parent router may have been disconnected. This section describes symptoms and diagnostic actions that a sleepy host node uses to maintain its network status.

Usual processing of a sleepy host node is to wake up periodically, transmit a MAC Poll command packet to its parent router, and receive the MAC acknowledgement packet in response. It may also transmit application packets at this time. If the application is expecting a response, the node should enter the fast poll state until the response is received normally or it has timed out.

If the sleepy host transmits an application packet and receives a response packet, that is sufficient confirmation that its network status has not changed and it can continue to operate normally.

That can be detected by the management entity on the node through the internal MAC COMM-status-indication with a status of UNAVAILABLE_KEY [802.15.4]. In this case, the sleepy host node should be waken to begin the PANA network key update process and retrieve the new security material from the Authentication Server. A sleepy node can proactively check for the new security material by doing a periodic key pull operation as described in Section 6.3.10.2.

The management entity on the sleepy host can detect loss of the radio link with its parent router if a data acknowledgement packet is received with an intermediate data link layer status of NO_ACK. In this case, the sleepy host node should be waken to attempt discovery and registration with a new parent router. The sleepy host can discover new parent routers through the MAC beacon mechanism as described in Step 2 of Section 6.3.5.1. After selecting a parent router, the sleepy host has already access to the necessary security material and IPv6 address configuration information. It registers its address and performs a secured MLE exchange with the new parent router (Steps 10 and 11 in Section 6.3.5.1).

If the sleepy host did not transmit any application data packets for a long duration, it may proactively verify its network status. For example, this can be done by transmitting an ICMPv6 echo request to its parent router. This should result in either the expected ICMPv6 echo response or one of error indications. The benefit of this processing is earlier detection of network changes including important update. The cost is an extra packet exchange. The cost-benefit depends on the actual deployment scenario and is therefore left up to the application.

If a sleepy host transmits application packets (including ICMPv6 echo request) to its parent node and does not receive the expected response or any MAC error indications, that is an indication that the network security material has been updated more than once. To recover from this status, the sleepy node cannot use the normal key update procedure. Instead it must rejoin the network by performing the initial MLE exchange (Step 5 in Section 6.3.5.1) with a new parent, requesting beacons, and discovering the new parent. The sleepy node performs "key pull" instead of a PANA authentication to obtain the new network key and performs a secured MLE exchange with the new parent (Step 11 in Section 6.3.5.1). The network rejoin procedure involves packet exchanges. A sleepy node should not perform the rejoin

procedure after it has failed to communicate with its parent node several times.

6.3.9. Network authentication

During the network join process, the node performs network authentication to ensure that the network is correct and acquire the necessary security credentials. Similarly, the network authenticates the node to ensure that the node is trusted and has the necessary security credentials to join the network.

The purpose of the authentication procedure is to provide mutual authentication resulting in:

- Preventing untrusted nodes without appropriate credentials from joining a trusted ZigBee IP network
- Preventing trusted nodes with appropriate credentials from joining an untrusted ZigBee IP network

The Authentication Server resides on the ZIP coordinator and is responsible for authenticating the nodes on the network. If the authentication is successful, the Authentication Server transmits the network security material to the joining node through the PANA protocol. The joining node becomes a participating node in the ZigBee IP network and can exchange IP packets with all other nodes in the network.

The authentication attempt must fail on the Authentication Server if the EAP-TLS server cannot authenticate the new node. This depends on the security credentials that are presented during the EAP-TLS handshake.

Additionally, the authentication attempt can fail based on application logic that is out of scope of this standard. An example of such application logic is a user button on the ZIP coordinator, where all join attempts are rejected unless they happen within a brief period of time after the button is pressed. Note that in such a scenario, a ZIP coordinator should still accept join attempts from nodes that have dropped off the network and are performing a rejoin. Another example of application logic is an explicit whitelist or blacklist of node IDs.

The joining node does not initially has access to the network security material. Therefore, it is not able to apply data link layer security for the packets exchanged during the authentication process. The enforcement point rules in the ZIP routers are described in Section 6.3.9.4 and they ensure that the packets involved in the PANA authentication are processed even though they are unsecured at the data link layer. The rules also ensure that any other incoming traffic that is not secured at the data link layer is discarded by a ZIP node and is not forwarded.

6.3.9.1. Authentication stack

Authentication can be viewed as a protocol stack as a layer encapsulates the layers above it. The ZIP authentication protocols are shown in relation to each other in the figure below.

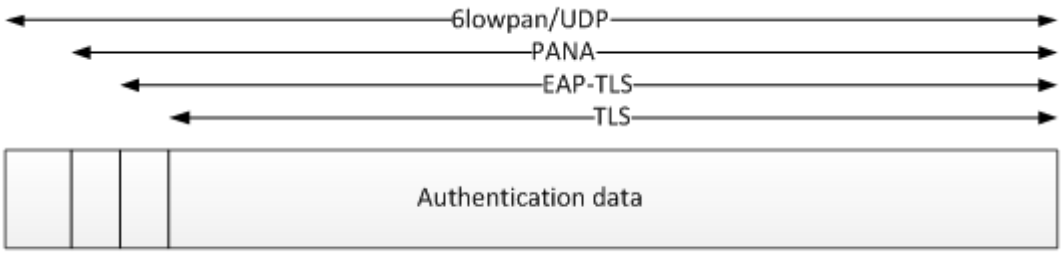


Figure 6-10: Authentication protocol stack within a ZigBee IP network

TLS [TLS] must be used at the highest layer and exchange authentication information. There are a cipher suite based

on the pre-shared key [TLS-CCM] and a cipher suite based on ECC [TLS-CCM-ECC].

EAP-TLS [EAP-TLS] must be used at the next layer to forward the TLS records for the authentication protocol.

The Extensible Authentication Protocol [EAP] must be used to provide the mechanisms for mutual authentication. EAP requires a way to transport EAP packets between the joining node and the node on which the Authentication Server resides. These nodes are not necessarily in radio range of each other, so it is necessary to have multihop support in the EAP transport method. The PANA protocol [PANA], [PANA-RELAY], which operates over UDP, must be used for this purpose. [EAP] specifies the derivation of a session key using the key hierarchy. [PANA] must derive the EAP master session key to be used for PANA authentication and encrypted key configuration.

PANA (RFC 5191) [PANA] and PANA relay [PANA-RELAY] must be used at the next layer.

- The joining node must act as a PANA client. (PaC)
- The parent node must act as a PANA relay (PRE) according to [PANA-RELAY], unless it is the Authentication Server. All ZIP routers must be capable of functioning in the PRE role.
- The Authentication Server node must act as a PANA Authentication Agent (PAA).
- The Authentication Server must be able to handle packets relayed according to [PANA-RELAY].

This network authentication process uses link-local IPv6 addresses for transport between the new node and its parent. If the parent is not the Authentication Server, it must then relay packets from the joining node to the Authentication Server and vice-versa using the PANA relay mechanism [PANA-RELAY]. The joining node must use its LL64 address as the source address for initial PANA authentication message exchanges.

6.3.9.2. Applicability statements

The applicability statements describe the relationship between various specifications.

.

6.3.9.2.1. Applicability statement for PSK TLS

[TLS-CCM] contains AEAD TLS cipher suits that are very similar to [TLS-PSK-GCM] whose AEAD part is detailed in [AEAD]. [TLS-PSK-GCM] references [TLS-GCM] and the original PSK cipher suite document [TLS-PSK], which references [TLS], which defines the TLS 1.2 messages.

6.3.9.2.2. Applicability statement for ECC TLS

[TLS-ECC-CCM] contains AEAD TLS cipher suits that are very similar to [TLS-ECC-GCM] whose AEAD part is detailed in [AEAD]. [TLS-ECC-GCM] references the original ECC cipher suite document [TLS-ECC] (RFC 4492), which references [TLS], which defines the TLS 1.2 messages.

6.3.9.2.3. Applicability statement for EAP-TLS and PANA

[EAP-TLS] specifies how [EAP] is used to package [TLS] messages into EAP packets. [PANA] specifies transportation for the EAP packets, additional configuration information carried in vendor specific attribute-value pairs (AVPs), and encrypted AVPs specified in [PANA-ENC] and this document. The proposed PRF and AUTH hashes based on SHA-256 are detailed in [IKEv2] (RFC 5996) and [IPSEC-HMAC] (RFC 4868).

6.3.9.3. PANA

6.3.9.3.1. PANA session

[PANA] specifies several phases for a PANA session. A ZigBee IP PANA session must be in either the

authentication or authorization phase. A ZigBee IP PANA session must always be initiated by the PaC. A ZigBee IP PANA session between the PaC and PAA must remain open for the purposes of network key update and maintenance.

6.3.9.3.2. PANA security association

The [PANA] specification is used by the PANA security association to generate the authentication key from the EAP Master Session Key and authenticate the final PANA messages using the authentication key. The [PANA-ENC] specification derives an encryption key, which must be used for an encryption key for network forwarding and network key index attached to data frames to nodes.

The PAA must maintain the following attributes as part of the secure association, in addition to those specified in [PANA]:

- EUI-64 of the PaC. This should be derived from the LL64 address of the PaC that is associated with this secure association. This information is used to uniquely identify the PaC and prevent duplicate sessions.
- Node Auth Counter. This is a 1-octet value that is stored on the PAA and forwarded to the PaC as part of the network security material.

6.3.9.3.3. PANA between a joining node (PaC) and parent node (PRE or PAA)

PANA messages between a joining node and its parent node must use single-hop unicast transmission in both directions with the following header addresses.

Table 6-22: PANA joining node header addresses

Address	Value	Comment
MAC address	64-bit	IEEE address of the Joining Node
IP address	LL64	Stateless autoconfigured link-local address of joining Node

Table 6-23: PANA parent node header addresses

Address	Value	Comment
MAC address	16-bit	Short address of the Parent Node
IP address	LL16	Stateless autoconfigured link-local address of parent node

6.3.9.3.4. PANA between a parent node (PRE) and Authentication Server

If a parent node and the Authentication Server are not the same node, the parent node must relay PANA messages exchanged between the joining node and the Authentication Server according to [PANA-RELAY]. The relaying is transparent to the joining node; as far as it is concerned, it is talking directly to the Authentication Server.

Relayed PANA messages between a parent node and the Authentication Server must use standard unicast transmission in both directions. Relayed PANA messages are secured at the link layer, thus satisfying the requirements of Section 3 of [PANA-RELAY] and avoiding the need for alternative packet protection.

6.3.9.3.5. Network security material transport

If the PANA authentication attempt is successful, the PAA must transmit the network security material to the joining

node in the final PANA Authentication Request message from the PAA to PaC. The network security material must be transported in the network key AVP (see Section 6.2.6.3) that is encrypted using the ENCR-ENCAP AVP [PANA-ENC]. The values of the Network Key and Index must contain the active network security material. The value of the Node Auth Counter must be taken from the PANA secure association state for that node.

At the point of completing the PANA authentication, the PAA must check if it has a duplicate secure association with this node. For purpose of checking the duplicate session information, the PAA should use the EUI-64 MAC address of the node. This attribute is derived from the LL64 address that is used by the PaC during the PANA authentication and is stored as part of the session information.

If a duplicate secure association is found, the PAA must take the Node Auth Counter value from the duplicate secure association, increment it (rollover to zero if necessary), and copy it into the new secure association. Furthermore, it must delete the old session information. Otherwise, the PAA should use a value of zero for the Node Auth Counter attribute in the secure association.

6.3.9.3.6. PaC address update

A ZIP node uses its link-local IP address during the PANA authentication process. As a result, the PAA secure association for each node contains the link-local address. After authentication is completed, the bootstrap process results in the configuration of a global unicast (GP16) IP address. [PANA] requires that if a node changes the IP address it uses for PANA communications, it must update that address at the PAA.

A ZIP router must update the GP16 address to the PAA server after completing its bootstrap process. This is achieved by transmitting any valid PANA packet to the PAA with the GP16 as the source IP address. Typically, a PANA Notification Request message is used for this purpose. After updating its IP address at the PAA, the node and PAA can communicate directly using the global unicast IP addresses.

A ZIP host should not update its IP address at the PAA server to its GP16 address. Since a ZIP host is typically a sleepy device, it is not always reachable from other nodes. Therefore, a ZIP host should continue to use its link-local IP address for communications with the PAA. These communications must be addressed to the PANA Relay entity at its parent router which relays them to the PAA.

6.3.9.4. EP (Enforcement Point) processing

All ZIP nodes must implement an EP (Enforcement Point) function. The EP acts by policing all traffic entering a node at all layers up to layer 4, thus effectively firewalling communication from all external nodes. The EP has filtering rules which are dependent on configuration and packet properties. The filtering rules are described below. The net effect of these rules is that all incoming MAC data packets that are not secured at the data link layer are discarded unless they contain an IPv6 packet with a destination address that belongs to the node and transmitted using the UDP protocol to the assigned PANA port number (716) or to the assigned MLE port number.

6.3.9.4.1. Data link layer filtering

- If the packet is protected by L2 security (network key), the EP must tag the packet as "L2 secure" and bypass any further layer filtering, allowing the packet through for further processing.

- If the packet is unprotected by L2 security (network key), the EP must tag the packet "L2 unsecure" and pass the packet for layer 3 filtering.

6.3.9.4.2. Network layer filtering

- If the packet is tagged as "L2 unsecure" and is a UDP message destined to this node, the EP must pass the packet for layer 4 filtering. (The destination IP address is a link-local address assigned to this node, including multicast addresses with link-local scope.)

- Otherwise, the EP must discard the packet.

6.3.9.4.3. Transport layer filtering

- If the packet is tagged as "L2 unsecure" and is a PANA message from a joining node (characterized as a UDP datagram with the destination port set to the assigned PANA port number and using link-local source and destination addresses) or an MLE packet (characterized as a UDP datagram with the destination port set to the assigned MLE port number), the EP must pass the packet to the respective application layer.

    - For MLE messages, the rules for handling of "L2 unsecure" messages are further described in Section 6.2.10.4. For PANA messages, no additional rules are necessary as the protocol does not rely on lower layer security.

- Otherwise, the EP must discard the packet.

6.3.10. Network key update

The network key can be updated by the Authentication Server at any time. The frequency and timing of such updates is implementation-specific. The network key must not be updated until the previous key update and activation are completed.

Typically, the Authentication Server would update the network security material for one of the following reasons:

- Periodically update the security material used for the MAC frame security as part of a standard operation procedure.

- Revoke network access to a node that possesses the current network security material

- Update the security material in anticipation of the Node Auth Counter reaching its maximum value for any ZIP node

The updated network security material is delivered to the authorized nodes via the PANA protocol. It can be delivered via either "push" or "pull" mechanism. The PAA "pushes" the updated network security material to all ZIP routers. The ZIP hosts are expected to "pull" the updated network security material from the PAA.

It is recommended that the Authentication Server update the security material periodically with duration between 1 day and 1 month. The reason to update the network security material at least once a month is to ensure that the node frame counter does not reach the maximum value. However, if the security material is updated too frequently, that will add control overhead on the network. Also, sleepy hosts can potentially miss the key updates and lose network connectivity. Therefore, it is recommended that a key update not be performed more often than once a day.

An example of a network key update process is shown in **Figure 6-11**.

6.3.10.1. PAA network security update procedure

The network security update program is triggered by the management entity on the Authentication Server.

A new network security material (see Section 6.2.6.2) is created by generating a new 128-bit network key. The sequence number for the key should be set to the sequence number of the active security material, incremented by one. If the current sequence number is 255, the new sequence number should roll over to 1. The Node Auth Counter must be reset to "0" for all nodes.

In addition to the new security material, the management entity may also provide a list of nodes, identified by their EUI-64 MAC addresses, which are on the network, but should not receive any further network security material.

Upon obtaining the new network security material, the PAA server performs the following actions:

1. The PAA deletes the PANA sessions corresponding to the nodes that are not eligible to receive further network security material.

2. The PAA "pushes" the new network security material to each node for which it has a secure association and also possesses the global unicast IP address.

3. The "push" involves transmitting a PANA Notification Request message. The PAA must include the updated network security material in a network key AVP (see Section 6.2.6.3) that is encrypted using the ENCR-ENCAP AVP [PANA-ENC].

After the PAA has completed the above processing, the management entity may activate the new security material.

During the time between the start of the key update process and completion of the activation, the PAA has two network security materials. Note that this includes two copies of the Node Auth counter for each node.

6.3.10.2. Network key pull

A ZIP node must initiate a network key pull when it detects the use of the new security material by another node. This happens when the node receives a packet that is secured at the MAC or MLE layer using a key index greater than what it currently possesses.

6.3.10.2.1. Request

The network key pull is initiated by transmitting a PANA Notification Request message to the PAA. The node should use the IP address registered with the PAA as the previous source address when transmitting this message (see Section 6.3.9.3.6). This is the LL64 address for a ZIP host or the GP16 address for a ZIP router.

A ZIP host must use its link-local IP address as the source address for this packet. It must transmit the packet to its parent router. The PANA Relay entity on the parent router will transparently relay this request and the response between the host and PAA.

A ZIP router must use the global unicast IP address that it has previously registered with the PAA as the source IP address and transmit the packet directly to the PAA.

If the ZIP node supports the Key Request AVP, it must include it in the PANA Notification Request packet. The nwk_key_req_flags should be set to a value of 1. The nwk_key_idx field should be populated with the value of the current active key index.

6.3.10.2.2. Response

The PANA Notification Answer message is transmitted from the PAA to the ZIP node in response to the above request.

If the incoming PANA Notification Request message does not include the Key request AVP or if the PAA does not

support the Key request AVP, the PAA must forward the new network security material if a key update is currently in progress or forward the current network security material otherwise.

If the incoming PANA Notification Request message includes the Key request AVP and the PAA supports this AVP, the PAA responds as follows:

- If the least significant bit of the nwk_key_req_flags field is 1:
  - If the nwk_key_idx field is equal to the active key index, the PAA must forward the new network security material. If a key update is in progress, it must transmit an empty response.
  - If the nwk_key_idx field is not equal to the active key index, the PAA must forward the active security material.
- If the least significant bit of the nwk_key_req_flags field is 0:
  - If the nwk_key_idx field is equal to the active key index, the PAA must forward the active security material.
  - Otherwise, the PAA must transmit an empty response.

The PAA must forward the current or new network security material in a network key AVP (see Section 6.2.6.3) that is encrypted using the ENCR-ENCAP AVP [PANA-ENC]. The Node Auth counter value must be set to 0 if the new security material is forwarded. Otherwise, the auth counter attribute from the PANA secure association corresponding to the ZIP node must be incremented by one and that value must be used in the network key AVP.

Note that if the PAA forwards the network security material to a new node that is joining the network (that is, in the final PANA Authentication Request message from the PAA to the PaC), it must always forward the current active network security material to the node.

A ZIP host may also periodically perform the network key pull procedure to check if there is updated security material at the PAA before that material is activated. If the ZIP host support the key request AVP, the host must contain the AVP in the Notification Request message and set the nwk_key_req_flags value to 0. However, if either the PaC or the PAA does not support the key request AVP, this operation should be done judiciously as each network key pull results in an increment of the Node Auth counter value until the next network key update resets it to zero. If the Auth counter reaches the maximum value for a node, then the node frame counters could reach their maximum limit and the node would be unable to communicate securely in the network.

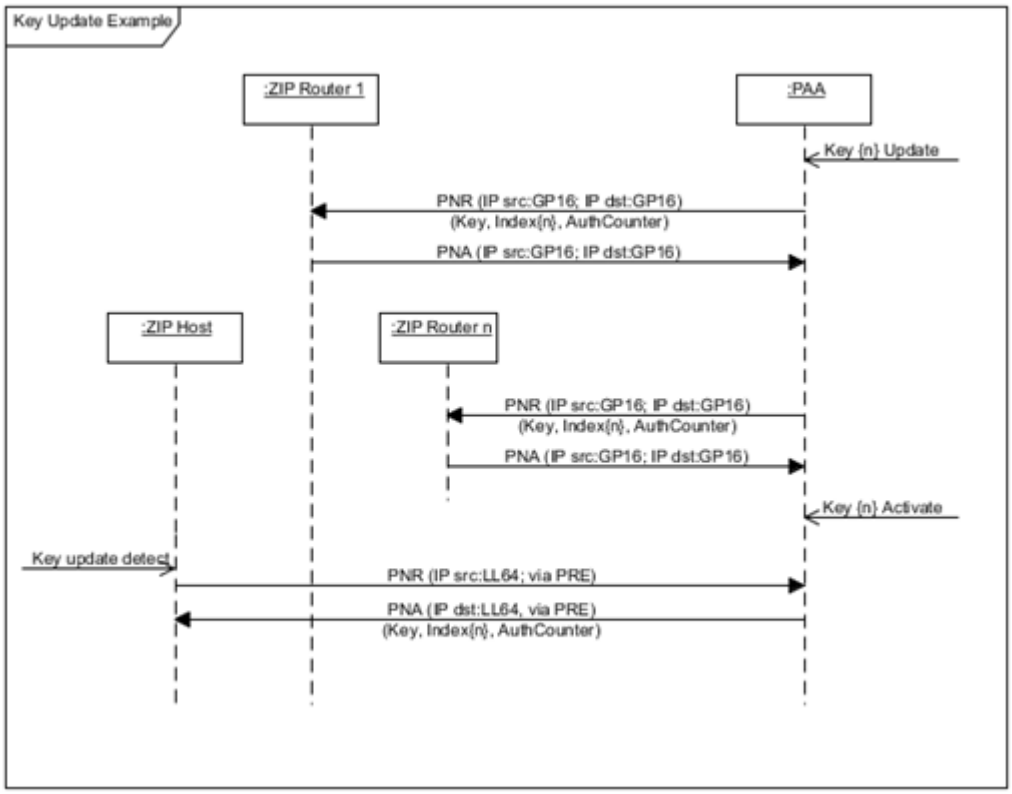


Figure 6-11: Network key update

6.3.10.3. Network key activation

The management entity on the Authentication Server is responsible for activating the new network security material.

It is recommended that this action be taken a short time after the new security material has been propagated to all non-sleepy nodes in the network. This is to allow sleepy nodes to "pull" the new security material from the PAA.

The activation of the network security material results in an update to the active MAC key and active MLE key as they are derived from the network security material.

The PAA simply activates the MAC and MLE security material whose key index matches the new network key sequence number. This will cause outgoing MAC frames and MLE messages from the PAA to be secured with the new key material.

When a ZIP node receives an incoming MLE message that is secured with a higher key index than its current active MLE key index, and that higher key index is equal to the alternate MLE key index, the node must swap the active alternate security materials.

When a ZIP node receives an incoming MAC message that is secured with a higher key index than its current active MAC key index, and the node possesses a MAC KeyDescriptor with that higher key index, the node updates the value of its active MAC key index to the higher key index.

When a ZIP node updates the active security material for either the MAC or MLE layer, the node management entity should also update the active security material for the other layer at the same time.

6.3.11. Node diagnostics

The ZIP stack makes available node management and diagnostic functionality for the data link layer, adaptation layer, and network layer. For each of these layers, the following information should be available. The node management functions shall always be available. However, the collection of diagnostics and statistics may be turned on or off.

The data link layer must implement the following attributes available to the node management application:

- EUI 64 address
- Short address
- Capability information
- Device PANID

The data link layer should make the following information available:

- Packets transmitted and received
- Octets transmitted and received
- Packets dropped on transmit and receive
- Security errors on receive
- Packet transmit failures due to no acknowledgement
- Packet transmit failures due to CSMA (channel access) failure
- Number of MAC retries

The adaptation layer should make the following information available:

- Packets transmitted and received
- Octets transmitted and received
- Fragmentation errors on receive

The network layer should make the following parameters available:

- IPv6 address list: List of IPv6 addresses that are assigned to the ZigBee IP interface on the node
- RPL instance list: List of RPL instances to which the node belongs
- RPL source routes list: List of RPL source routes, for each RPL instance, that are available on the node
- RPL parent list: Set of RPL parents, for each RPL instance, on the node

The management layer should make the following parameters available:

- NetworkID: Identifier of the ZigBee IP network to which this node belongs

- MLE neighbor table: List of neighbor node addresses and the associated link quality information

6.3.12. Persistent data

Devices operating in the field may be reset either manually or programmatically by maintenance personnel, or may be reset accidentally for any reasons, including localized or network-wide power failures, battery replacement during normal maintenance, and impact. Network operation needs to be restarted without intervention by devices which are reset. Devices which are reset need to have the ability to restart without user intervention.

ZIP routers and ZIP hosts should store the network identifier in non-volatile storage. This allows the node to recover from an unscheduled reset without user intervention. In addition, ZIP routers and ZIP hosts should store the PANA security session information in non-volatile storage to make the rejoin process more efficient. A node that is restoring previous configuration after a reset should not reuse its previous GP16 IPv6 address (or MAC short address) without checking for uniqueness again.

The ZIP coordinator must store information necessary to restore the ZIP network configuration after a reset, in persistent storage. The information includes:

- ZIP NetworkID value
- PANA security session information for each of the authenticated nodes
- Network key material
- Information necessary to recreate information in the Router Advertisement packet. This includes the ABRO version, prefix, and context information.
- Information necessary to recreate DIO packets. This includes the RPL instance ID and DAG version.

The method by which data is made to persist is outside of scope of this specification.

6.4. Constants and attributes

This section specifies the constants and attributes required by the ZigBee IP protocol suite.

6.4.1. Attributes

A ZIP node must configure the following attribute values.

Table 6-24: ZIP node configuration

Attribute	Description	Value
MIN_6LP_CID_COUNT	Minimum number of 6LoWPAN header compression context identifiers that are supported by a node	4
MIN_6LP_PREFIX	Minimum number of 6LoWPAN prefixes that are supported by a node	2
MIN_RPL_INSTANCE_COUNT	Minimum number of RPL instances that a ZIP router is capable of participating in	2

MLE_ADV_INTERVAL	Time interval between transmissions of successive MLE Advertisement packets by a ZIP router	16 seconds
MLE_ADV_TIMEOUT	Time interval after which a ZIP router should remove a node from its MAC device table if it has not received MLE advertisements from that neighbor node containing this node as a neighbor	54 seconds
MLE_MAX_ALLOW_JOIN_TIME	Maximum period of time a ZIP router should keep the Allow Join flag enabled without additional commands	30 minutes
RPL_INSTANCE_LOST_TIMEOUT	Period of time a ZIP router can lose connectivity to an RPL instance before removing itself from that instance	1200 seconds
RPL_MIN_DAO_PARENT	Number of DAO parents that an RPL router should be able to support	2
RPL_MAX_RIO	Maximum number of route information options that should be included in a DIO packet	3
RPL_MTU_EXTENSION	Additional number of octets added to the link layer MTU for IP packets transmitted over the RPL tunnel interface	100 bytes
RPL_MAX_PIO	Maximum number of prefix information options that can be included in a DIO packet	1
EAP_TLS_MTU	Maximum size of TLS data in the EAP payload when using EAP-TLS fragmentation	512 octets
MAC_MIN_INDIRECT_TIMEOUT	Minimum period of time a ZIP router buffers an IPv6 packet for indirect transmission at the data link layer	1 second
MAC_MIN_INDIRECT_BUFFER	Minimum number of IPv6 packets that a ZIP router can buffer for indirect transmission at the data link layer	1
MAC_MAX_FAST_POLL_TIME	Maximum duration between consecutive MAC polls when a sleepy host node is in the fast poll state	500 ms

MAC_ MAX_POLL_TIME	Maximum duration of inactivity from a sleepy host after which a ZIP router can remove the entry from its MAC device table	1 day
MAC_MAX_NWK_KEYS	Number of MAC keys that are stored by a node	2
MAC_MIN_DEV_TBL	Minimum number of entries a ZIP router should support in its MAC device table	6
MCAST_MIN_TBL_SIZE	Minimum number of trickle multicast sequence values that can be stored in a ZIP router	8

6.5. Annex-1

This section contains informative clarifications used to aid implementation of the specification. The clarifications are then to clarify explicit or implicit normative requirements. All normative requirements are contained in the normative sections of this document and the specifications are referenced in this document.

6.5.1. PANA [PANA]

6.5.1.1. Packets

PANA packets should be a multiple of 4 octets in size.

6.5.1.2. AVPs

PANA AVPs can appear in any order, except for the AUTH AVP, which must be the final AVP. Octet string AVPs (Auth, EAP-Payload, and Nonce) must be aligned to 4 octets, without the padding being included in the field length. Other AVPs are automatically aligned.

6.5.1.3. Transactions

PANA packet transactions form the basis of EAP packet forwarding. PANA transactions occur between a PANA client (PaC) and PANA Authentication Agent (PAA) and can be relayed via a PANA relay (PRE). A relayed session essentially carries the same EAP and TLS information, but the PANA session is carried between three entities.

An EAP response should be piggy-backed on the PANA answer. However, implementation should assume that an EAP response may alternatively be carried in a separate PAR initiated by the PaC followed by a PAN from the PAA.

6.5.1.4. PANA key generation

[PANA] and [PANA-ENC] specify how the PANA_AUTH_KEY and PANA_ENCR_KEY are generated. This section provides additional guidance.

```
PANA_AUTH_KEY = prf+(MSK, "IETF PANA", |I_PAR|I_PAN|PaC_nonce|PAA_nonce|Key_ID);
PANA_ENCR_KEY = prf+(MSK, "IETF PANA Encryption Key",
|I_PAR|I_PAN|PaC_nonce|PAA_nonce|Key_ID);
```

The PRF function needs to be iterated only once as the PANA_AUTH_KEY and PANA_ENCR_KEY lengths are the same as the underlying hash (that is, 32 octets). Therefore, the TLS PRF function can be used simply by concatenating 0x01 to the string:

```
prf+(K, S) = P_hash(K, S | 0x01)
```

The string "IETF PANA" is not null-terminated since it has a length of 9 octets. The string "IETF PANA Encryption Key" is not also null-terminated since it has a length of 24 octets.

6.5.1.5. IKEv2 prf+ function used in PANA

All PANA transactions use the prf+ function specified in [IKEv2] (RFC 5996). In the following description, "|" indicates concatenation.

prf+ is defined as:

```
prf+ (K,S) = T1 | T2 | T3 | T4 | ...
```

where:

```
T1 = prf (K, S | 0x01)
T2 = prf (K, T1 | S | 0x02)
T3 = prf (K, T2 | S | 0x03)
T4 = prf (K, T3 | S | 0x04)
...
```

This continues until all data needed to compute required keys has been output from prf+.

The PRF used is the IPsec PRF function PRF-HMAC-SHA-256 specified in [IPSEC-HMAC].

Note that the HMAC key size (Section 2.1.1) specifies that HMAC key size must be the size of the underlying hash. So in this case, the PANA_AUTH_KEY size is 32 octets (output from SHA-256).

Note also that if the output is always the size of the underlying hash or less, the prf+ function only has to be iterated once.

```
prf+(K, S) ≡ P_hash(K, S | 0x01)
```

6.5.2. TLS

6.5.2.1. TLS PSK

6.5.2.1.1. Premaster secret

[TLS-PSK] states: "if the PSK is N octets long, concatenate a uint16 with the value N (N = 0 octets for the plain PSK), the second uint16 with the value N and the PSK itself"

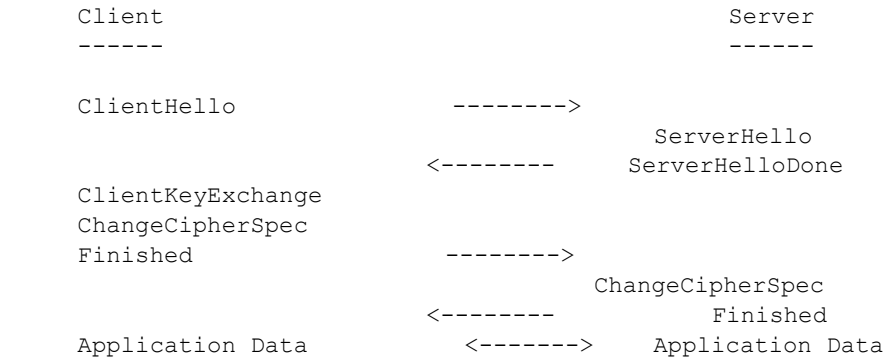
Premaster Secret = 00 10 || 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 || 00 10 || CF CE CD CC CB CA C9 C8 C7 C6 C5 C4 C3 C2 C1 C0

where || is the concatenation operator.

Note that the concatenation of the length with the data represents a TLS variable length vector <0..2^16-1>.

6.5.2.1.2. PSK key exchange

The TLS PSK key exchange is shown below. The optional elements are not shown.

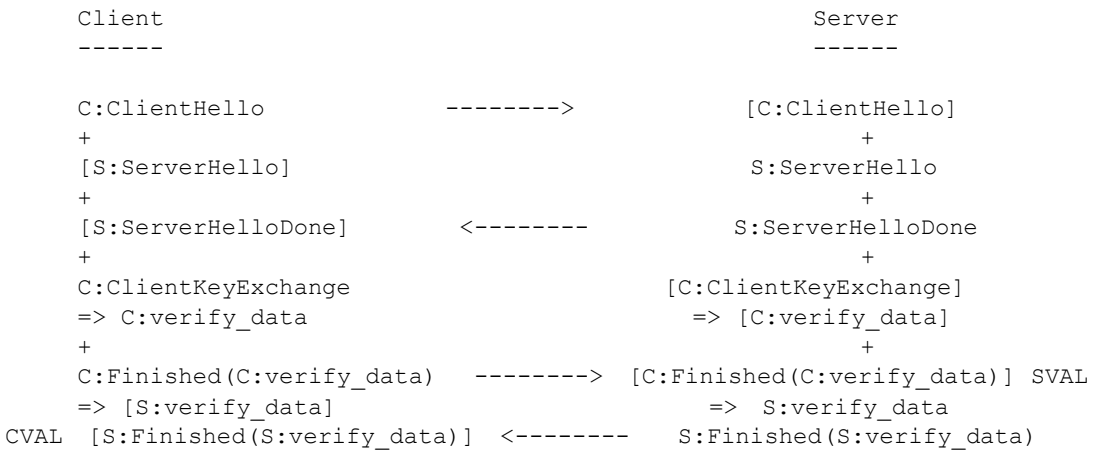


6.5.2.1.3. PSK data verification

In the following diagram:

- '+' indicates concatenation.
- '[]' indicates the recipient of data as opposed to the originator of data, or reconstructed data for `verify_data`.
- '=>' indicates calculation.
- The final `Finished` message included in the concatenation of messages is used as cleartext.
- Validation is performed on the server at `SVAL`, and at the client at `CVAL`.
- `verify_data = PRF(master_secret, finished_label, Hash(handshake_messages))`
- `verify_data_length` is 12 octets.
- For `Finished` messages transmitted by the client, the finished_label is the string "client finished".
- For `Finished` messages transmitted by the server, the finished_label is the string "server finished".

Data verification is performed over the following handshake messages:



6.5.2.2. TLS ECC

6.5.2.2.1. ECC key exchange

The TLS ECC key exchange is shown below. The optional elements are not shown. Since authentication is mutual, if this cipher suite is used, the TLS server must require client authentication, that is, client's certificate is required.

```
Client                                          Server
------                                          ------

ClientHello                --------->
                                                ServerHello
                                                Certificate
                                          ServerKeyExchange
                                         CertificateRequest
                           <---------      ServerHelloDone
Certificate
ClientKeyExchange
CertificateVerify
ChangeCipherSpec
Finished                   --------->
                                           ChangeCipherSpec
                           <---------             Finished
Application Data             <------->     Application Data
```

6.5.2.2.2. ECC data verification

In the following diagram:

- '+' indicates concatenation.
- '[]' indicates the recipient of data as opposed to the originator of data, or reconstructed data for `verify_data`.
- '=>' indicates calculation.
- The final `Finished` message included in the concatenation of messages is used as cleartext.
- Validation is performed on the server at `SVAL`, and at the client at `CVAL`.
- `verify_data = PRF(master_secret, finished_label, Hash(handshake_messages))`
- `verify_data_length` is 12 octets.
- For `Finished` messages transmitted by the client, the finished_label is the string "client finished".
- For `Finished` messages transmitted by the server, the finished_label is the string "server finished".

Data verification is performed over the following handshake messages:

```
Client                                             Server
------                                              ------

C:ClientHello              --------->            [C:ClientHello]
+                                                       +
[S:ServerHello]                                   S:ServerHello
+                                                       +
[S:Certificate]                                   S:Certificate
+                                                       +
[S:ServerKeyExchange]                          S:ServerKeyExchange
+                                                       +
[S:CertificateRequest]                        S:CertificateRequest
+                                                       +
[S:ServerHelloDone]          <---------          S:ServerHelloDone
+                                                       +
C:Certificate                                    [C:Certificate]
+                                                       +
C:ClientKeyExchange                           [C:ClientKeyExchange]
+                                                       +
```

```
     C:CertificateVerify                      [C: CertificateVerify]
     => C:verify_data                            => [C:verify_data]
     +                                                    +
     C:Finished(C:verify_data)   --------> [C:Finished(C:verify_data)] SVAL
     => [S:verify_data]                           =>  S:verify_data
CVAL  [S:Finished(S:verify_data)] <--------    S:Finished(S:verify_data)
```

6.5.2.3. TLS ECC additional information

6.5.2.3.1. ClientHello extensions

`ClientHello` has extensions, which can be identified as additional data being present after the `compression_methods` field.

The extensions from [TLS-ECC] Section 5.1 are as follows:

- `elliptic_curves` (10), size 4:
    - `EllipticCurveList` length: 2
    - One `NamedCurve`: `secp256r1` (0x0017)
- `ec_point_formats` (11), size 2
    - `ECPointFormatList` length: 1
    - One `ECPointFormat`: `uncompressed` (0x00)

The extensions from [TLS] are as follows:

- `signature_algorithms` (13), size 4:
    - `SignatureAndHashAlgorithm` length: 2
    - hash `sha256` (0x04)
    - signature `ecdsa` (0x03)

6.5.2.3.2. ServerHello extensions

`ServerHello` has extensions, which can be identified as additional data being present after the `compression_method` field.

The extensions from [TLS-ECC] Section 5.2 are as follows:

- `ec_point_formats` (11), size 2:
    - `ECPointFormatList` length: 1
    - One `ECPointFormat`: `uncompressed` (0x00)

6.5.2.4. TLS CCM parameters

The following parameters are used for the CCM AEAD cipher in the TLS-PSK and TLS-ECC cipher suites, as described in [AEAD].

Table 6-25: TLS CCM parameters

Parameter	Value	Description
M	8	MIC length
L	3	Length length

6.5.3. Examples of transactions

The transactions are generally layered:

- TLS records
- EAP packets
- PANA packets

The PANA session wraps the EAP session, which wraps the TLS handshake transactions.

6.5.3.1. Syntax

The syntax used is similar to C structure syntax. All fields are clearly sized and where the field value is fixed for the packet, the value is stated.

6.5.3.2. TLS

TLS records are typically concatenated as described in the handshake transactions. Each record contains plaintext data for the TLS Handshake and TLS Change Cipher Spec records and ciphertext data for TLS Handshake records.

6.5.3.3. EAP

EAP packets carry the requests and the responses between the EAP entities (that is, Peer and Authenticator). The EAP protocol allows packets to be fragmented and reassembled. EAP-TLS is a specific EAP method used which encapsulates TLS records into the EAP protocol and defines key derivation.

6.5.3.4. PANA

PANA packet transactions form the basis of higher layer packet forwarding. PANA transactions can occur between the PANA client (PaC) and PANA Authentication Agent (PAA) and can be relayed via a PANA relay (PRE).

The PANA session for a PaC to a PAA is shown below. A relayed session essentially carries the same EAP and TLS information, but the PANA session is between three entities.

The sequence shown below assumes that the EAP response can be piggy-backed on the PANA answer. This may not always be the case and implementation should assume that an EAP response may alternatively be carried in a separate PAR initiated by the PaC followed by a PAN from the PAA.

PANA packets should be a multiple of 4 octets in size.

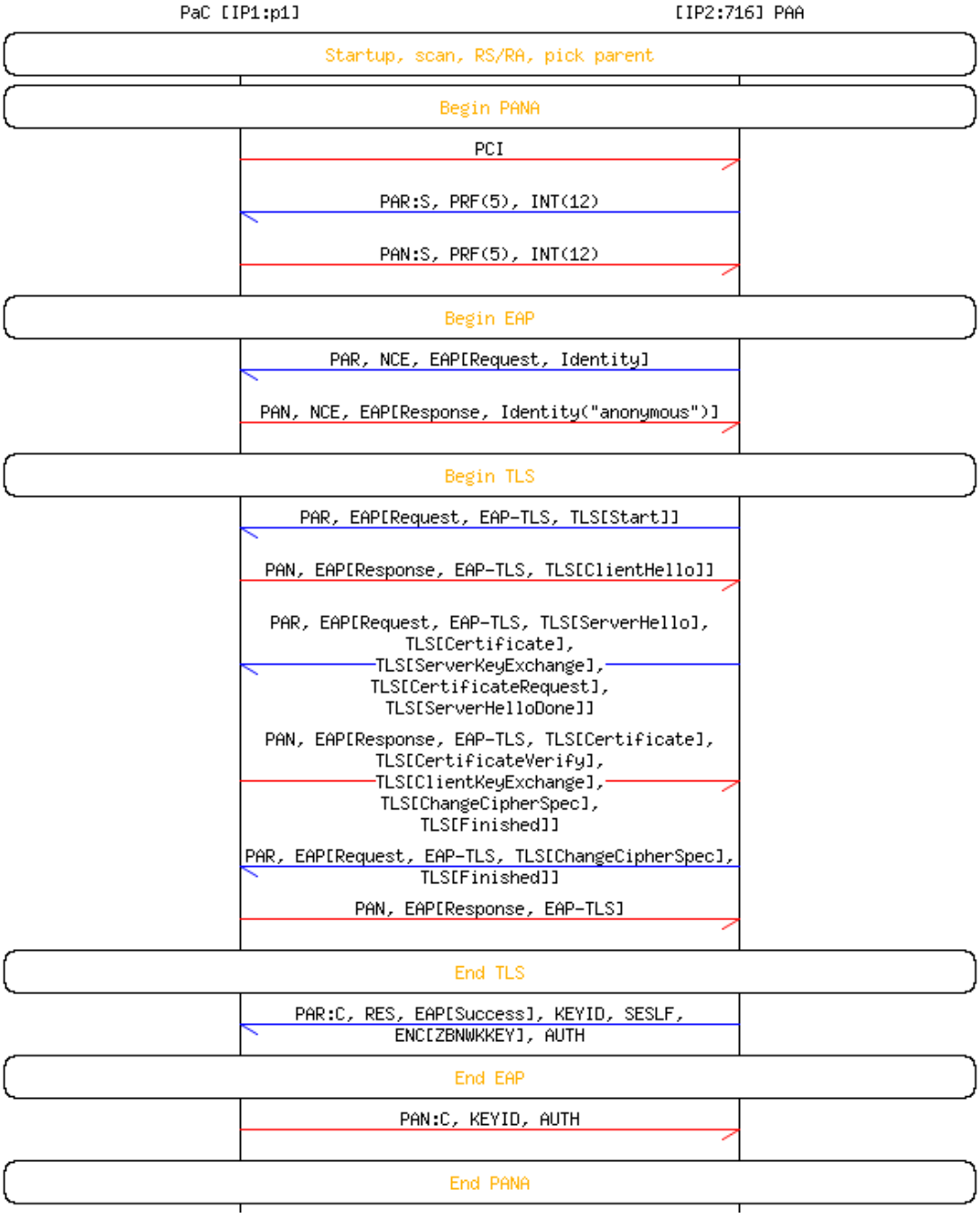


Figure 6-12: ECC PANA exchange

6.5.3.5. PCI (from a PaC to a PAA)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 16; /* 16H */
    uint16 flags = 0x0000;
    uint16 type = 1; /* PCI */
    uint32 session_id = 0;
    uint32 seq_no = 0;
};
```

6.5.3.6. PANA start (from the PAA to the PaC)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 52; /* 16H + (8H + 4P) + (8H + 4P) + (8H + 4P) */
   uint16 flags = 0xC000; /* Request, start */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id; /* Chosen by PAA */
   uint32 seq_no = paa_seq_no; /* Random number chosen by PAA */
   /* If PRF_HMAC_SHA2_256 is the only PRF, the following AVP may be optional */
   struct PANAAVP {
      uint16 code = 6; /* PRF algorithm */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 prf_algorithm = 5;
   }
   /* If AUTH_HMAC_SHA2_256_128 is the only integrity algorithm, the following AVP
may be optional */
   struct PANAAVP {
      uint16 code = 3; /* Integrity algorithm */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 integrity_algorithm = 12;
   }
   /* If AES-CTR is the only encryption, the following AVP may be optional */
   struct PANAAVP {
      uint16 code = 12; /* Encryption algorithm */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 encryption_algorithm = 1;
   }
};
```

6.5.3.7. PANA start (from the PaC to the PAA)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 52; /* 16H + (8H + 4P) + (8H + 4P) + (8H + 4P) */
   uint16 flags = 0x4000; /* Answer, Start */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id; /* Returned by PaC */
   uint32 seq_no = paa_seq_no; /* Returned by PaC */
   /* If PRF_HMAC_SHA2_256 is the only PRF, the following AVP may be optional */
   struct PANAAVP {
      uint16 code = 6; /* PRF algorithm */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 prf_algorithm = 5;
   }
   /* If AUTH_HMAC_SHA2_256_128 is the only integrity algorithm, the following AVP
may be optional */
   struct PANAAVP {
      uint16 code = 3; /* Integrity algorithm */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 integrity_algorithm = 12;
```

```
    }
    /* If AES-CTR is the only encryption, the following AVP may be optional */
    struct PANAAVP {
       uint16 code = 12; /* Encryption algorithm */
       uint16 flags = 0;
       uint16 length = 4;
       uint16 rsvd = 0;
       uint32 encryption_algorithm = 1;
    }
};
```

6.5.3.8. EAP identifier request (from the PAA to the PaC)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 56; /* 16 + (8H + 16P) + (8H + 5P + 3Pd) */
    uint16 flags = 0x8000; /* Request */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id;
    uint32 seq_no = paa_seq_no + 1; /* Increment sequence number */
    struct PANAAVP {
       uint16 code = 5; /* Nonce */
       uint16 flags = 0;
       uint16 length = 16;
       uint16 rsvd = 0;
       uint8 nonce[16];
    }
    /* The following AVP may be optional */
    struct PANAAVP {
       uint16 code = 2; /* EAP Payload */
       uint16 flags = 0;
       uint16 length = 5; /* 5P */
       uint16 rsvd = 0;
       struct EAPReqUnfrag {
          uint8 code = 1; /* EAPReq */
          uint8 identifier = idseq;
          uint16 length = 5; /* inc. 5H + 0P */
          uint8 type = 1; /* EAP-Identity */
       };
       struct AVPPad {
       uint8 bytes[3];
     };
    };
};
```

6.5.3.9. EAP identifier response (from the PaC)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 64; /* 16H + (8H + 16P) + (8H + 14P + 2Pd) */
    uint16 flags = 0x0000; /* Answer */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id; /* Returned by PaC */
    uint32 seq_no = paa_seq_no + 1; /* Returned by PaC */
    struct PANAAVP {
       uint16 code = 5; /* Nonce */
       uint16 flags = 0;
       uint16 length = 16;
       uint16 rsvd = 0;
       uint8 nonce[16];
    }
    /* The following AVP may be optional */
```

```
    struct PANAAVP {
       uint16 code = 2; /* EAP Payload */
       uint16 flags = 0;
       uint16 length = 14;
       uint16 rsvd = 0;
       struct EAPRspUnfrag {
          uint8 code = 2; /* EAPRsp */
          uint8 identifier = idseq; /* Corresponds to request */
          uint16 length = 14; /* inc. 5H + 9P */
          uint8 type = 1; /* EAP-Identity */
          /* Anonymous NAI */
          uint8 identity[] = "anonymous";
       };
       struct AVPPad {
       uint8 bytes[2];
     };
    };
};
```

6.5.3.10. TLS start (from the PAA to the PaC)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 32; /* 16H + (8H + 6P + 2Pd) */
    uint16 flags = 0x8000; /* Request */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id;
    uint32 seq_no = paa_seq_no + 2; /* Increment sequence number */
    struct PANAAVP {
       uint16 code = 2; /* EAP Payload */
       uint16 flags = 0;
       uint16 length = 6;
       uint16 rsvd = 0;
       struct EAPReqUnfrag {
          uint8 code = 1;
          uint8 identifier = idseq + 1;
          uint16 length = 6; /* inc. 6H + 0P */
          uint8 type = 13; /* EAP-TLS */
          uint8 flags = 0x20; /* Start */
       };
       struct AVPPad {
       uint8 bytes[2];
     };
    };
};
```

6.5.3.11. PSK TLS ClientHello (from the PaC to the PAA)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 80; /* 16H + (8H + 56P) */
    uint16 flags = 0x0000; /* Answer */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id; /* Returned by PaC */
    uint32 seq_no = paa_seq_no + 2; /* Returned by PaC */
    struct PANAAVP {
       uint16 code = 2; /* EAP Payload */
       uint16 flags = 0;
       uint16 length = 56;
       uint16 rsvd = 0;
       struct EAPRspUnfrag {
          uint8 code = 2;
```

```
            uint8 identifier = idseq + 1; /* Corresponds to request */
            uint16 length = 56; /* inc. 6H + (5H + 45P) */
            uint8 type = 13; /* EAP-TLS */
            uint8 flags = 0x00;
            struct TLSPlaintext {
               uint8 type = 22; /* Handshake */
               uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
               uint16 length = 45; /* 4H + 41P */
               struct Handshake {
                  uint8 msg_type = 1; /* ClientHello */
                  uint24 length = 41; /* 2P + 32P + 1P + 4P + 2P */
                  struct ClientHello {
                     struct ProtocolVersion {
                        uint8 major = 0x03;
                        uint8 minor = 0x03; /* TLS 1.2? */
                     } client_version;
                     struct Random {
                        uint32 gmt_unix_time;
                        uint8 random_bytes[28];
                     } random;
                     struct SessionID<0..32> {
                        uint8 length = 0; /* NULL */
                     } session_id;
                     struct <2..2^16-2> {
                        uint16 length = 2;
                        struct CipherSuite {
                           uint8 bytes[2] = {0x00, 0xC6};
                        } cipher_suites[1];
                     };
                     struct <1..2^8-2> {
                        uint8 length = 1;
                        uint8 compression_methods[1] = {0};
                     }
                     /* NOTE: extensions will be needed for public key cipher suite
*/
                     struct { }; /* No extensions */
                  };
               };
            };
         };
      };
   };
};
```

6.5.3.12. ECC TLS ClientHello (from the PaC to the PAA)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 108; /* 16H + (8H + 82P + 2Pd) */
   uint16 flags = 0x0000; /* Answer */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id; /* Returned by PaC */
   uint32 seq_no = paa_seq_no + 2; /* Returned by PaC */
   struct PANAAVP {
      uint16 code = 2; /* EAP Payload */
      uint16 flags = 0;
      uint16 length = 82;
      uint16 rsvd = 0;
      struct EAPRspUnfrag {
         uint8 code = 2;
         uint8 identifier = idseq + 1; /* Corresponds to request */
         uint16 length = 82; /* inc. 6H + (5H + 77P) */
         uint8 type = 13; /* EAP-TLS */
         uint8 flags = 0x00;
```

```
   struct TLSPlaintext {
      uint8 type = 22; /* Handshake */
      uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
      uint16 length = 71; /* 4H + 67P */
      struct Handshake {
         uint8 msg_type = 1; /* ClientHello */
         uint24 length = 67; /* 2P + 32P + 1P + 8P + 2P + 22P */
         struct ClientHello {
            struct ProtocolVersion {
               uint8 major = 0x03;
               uint8 minor = 0x03; /* TLS 1.2? */
            } client_version;
            struct Random {
               uint32 gmt_unix_time;
               uint8 random_bytes[28];
            } random;
            struct SessionID<0..32> {
               uint8 length = 0; /* NULL */
            } session_id;
            struct <2..2^16-2> {
               uint16 length = 4;
               struct CipherSuite {
                  uint8 bytes[2] = {0xC0, 0xC6};
               } cipher_suites[1];
               struct CipherSuite {
                  uint8 bytes[2] = {0x00, 0xC6};
               } cipher_suites[1];
            };
            struct <1..2^8-2> {
               uint8 length = 1;
               uint8 compression_methods[1] = {0};
            }
            struct { /* ECC extensions */
               uint16 length = 22;
               struct EllipticCurvesExtension {
                  uint16 type = 10; /* elliptic_curves */
                  uint16 length = 4;
                  uint16 eclength = 2;
                  uint16 ec = 23; /* secp256r1 */
               };
               struct ECPointFormatsExtension {
                  uint16 type = 11; /* ec_point_formats */
                  uint16 length = 2;
                  uint8 pflength = 1;
                  uint8 pf = 0; /* uncompressed */
               };
               struct SignatureAlgorithmsExtension {
                  uint16 type = 13; /* signature_algorithms */
                  uint16 length = 4; /* 2? */
                  struct <2..2^16-2> {
                     uint16 length = 2;
                     struct SignatureAndHashAlgorithm {
                        uint8 hash = 0x04; /* sha256 */
                        uint8 signature = 0x03; /* ecdsa */
                     } signature_and_hash_algorithm[1];
                  };
               };
     };
          };
       };
   };
};
struct AVPPad {
```

```
      uint8 bytes[2];
    };
   };
};
```

6.5.3.13. PSK TLS ServerHello, ServerHelloDone (from the PAA to the PaC)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 88; /* 16H + (8H + 61P + 3Pd) */
   uint16 flags = 0x8000; /* Request */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id;
   uint32 seq_no = paa_seq_no + 3; /* Increment sequence number */
   struct PANAAVP {
      uint16 code = 2; /* EAP Payload */
      uint16 flags = 0;
      uint16 length = 61;
      uint16 rsvd = 0;
      struct EAPReqUnfrag {
         uint8 code = 1;
         uint8 identifier = idseq + 2;
         uint16 length = 61; /* inc. 6H + (5H + 50P) */
         uint8 type = 13; /* EAP-TLS */
         uint8 flags = 0x00;
         struct TLSPlaintext {
            uint8 type = 22; /* Handshake */
            uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
            uint16 length = 50; /* (4H + 42P) + (4H + 0P) */
            struct Handshake {
               uint8 msg_type = 2; /* ServerHello */
               uint24 length = 42; /* 2P + 32P + 5P + 2P + 1P */
               struct ServerHello {
                  struct ProtocolVersion {
                     uint8 major = 0x03;
                     uint8 minor = 0x03; /* TLS 1.2? */
                  } server_version;
                  struct Random {
                     uint32 gmt_unix_time;
                     uint8 random_bytes[28];
                  } random;
                  struct SessionID<0..32> {
                     uint8 length = 4; /* Arbitrary for now */
                     uint8 bytes[4];
                  } session_id;
                  struct CipherSuite {
                     uint8 bytes[2] = {0x00, 0xC6};
                  } cipher_suite;
                  uint8 compression_method = {0};
                  /* NOTE: extensions will be needed for public key cipher suite
*/
                  struct { }; /* No extensions */
               };
            };
            struct Handshake {
               uint8 msg_type = 14; /* ServerHelloDone */
               uint24 length = 0;
               struct ServerHelloDone { }; /* Empty */
            };
         };
      };
      struct AVPPad {
      uint8 bytes[3];
```

```
        };
    };
};
```

6.5.3.14. ECC TLS ServerHello, Certificate, ServerKeyExchange, CertificateRequest, ServerHelloDone (from the PAA to the PaC)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 844; /* 16H + (8H + 61P + 3Pd) */
    uint16 flags = 0x8000; /* Request */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id;
    uint32 seq_no = paa_seq_no + 3; /* Increment sequence number */
    struct PANAAVP {
        uint16 code = 2; /* EAP Payload */
        uint16 flags = 0;
        uint16 length = 820;
        uint16 rsvd = 0;
        struct EAPReqUnfrag {
            uint8 code = 1;
            uint8 identifier = idseq + 2;
            uint16 length = 820; /* inc. 6H + (5H + 50P) */
            uint8 type = 13; /* EAP-TLS */
            uint8 flags = 0x00;
            struct TLSPlaintext {
                uint8 type = 22; /* Handshake */
                uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
                uint16 length = 50; /* (4H + 42P) + (4H + 0P) */
                struct Handshake {
                    uint8 msg_type = 2; /* ServerHello */
                    uint24 length = 78; /* 2P + 32P + 5P + 2P + 1P */
                    struct ServerHello {
                        struct ProtocolVersion {
                            uint8 major = 0x03;
                            uint8 minor = 0x03; /* TLS 1.2? */
                        } server_version;
                        struct Random {
                            uint32 gmt_unix_time;
                            uint8 random_bytes[28];
                        } random;
                        struct SessionID<0..32> {
                            uint8 length = 32; /* Arbitrary for now */
                            uint8 bytes[32];
                        } session_id;
                        struct CipherSuite {
                            uint8 bytes[2] = {0xC0, 0xC6};
                        } cipher_suite;
                        uint8 compression_method = {0};
                        struct { /* ECC extensions */
                            uint16 length = 6;
                            struct ECPointFormatsExtension {
                                uint16 type = 11; /* ec_point_formats */
                                uint16 length = 2;
                                uint8 pflength = 1;
                                uint8 pf = 0; /* uncompressed */
                            };
                        };
                    };
                };
                struct Handshake {
                    uint8 msg_type = 11; /* Certificate */
```

```
                uint24 length = 559;
                uint24 certificates_length = 556;
                uint24 certificate length = 553;
                uint8 certificate[0][553]; /* Single certificate */
             };
             struct Handshake {
                uint8 msg_type = 12; /* ServerKeyExchange */
                uint24 length = 144;
                uint8 server_key_exchange[144]; /* Single certificate */
                struct ServerHelloDone { }; /* Empty */
             };
             struct Handshake {
                uint8 msg_type = 13; /* CertificateRequest */
                uint24 length = 10;
                struct <2..2^8-1> {
                   uint8 length = 1;
                   uint8 certificate_types = 0x40; /* ecdsa_sign */
                };
                struct <2..2^16-2> {
                   uint16 length = 2;
                   struct SignatureAndHashAlgorithm {
                      uint8 hash = 0x04; /* sha256 */
                      uint8 signature = 0x03; /* ecdsa */
                   } signature_and_hash_algorithm[1];
                };
                struct <2..2^16-1> {
                   uint16 length = 0;
                };
             };
             struct Handshake {
                uint8 msg_type = 14; /* ServerHelloDone */
                uint24 length = 0;
                struct ServerHelloDone { }; /* Empty */
             };
          };
       };
       struct AVPPad {
       uint8 bytes[3];
       };
    };
};
```

6.5.3.15. TLS ClientKeyExchange and ChangeCipherSpec, Finished (from the PaC to the PAA)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 88; /* 16H + (8H + 62P + 2Pd) */
    uint16 flags = 0x0000; /* Answer */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id; /* Returned by PaC */
    uint32 seq_no = paa_seq_no + 3; /* Returned by PaC */
    struct PANAAVP {
       uint16 code = 2; /* EAP Payload */
       uint16 flags = 0;
       uint16 length = 62;
       uint16 rsvd = 0;
       struct EAPRspUnfrag {
          uint8 code = 2;
          uint8 identifier = idseq + 2; /* Corresponds to request */
          uint16 length = 62; /* inc. 6H + (5H + (4H + 4P)) + (5H + 1P) + (5H + 32P)
*/
          uint8 type = 13; /* EAP-TLS */
          uint8 flags = 0x00;
```

```
            struct TLSPlaintext{
               uint8 type = 22; /* Handshake */
               uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
               uint16 length = 4;
               struct Handshake {
                  uint8 msg_type = 16; /* ClientKeyExchange */
                  uint24 length = 4;
                  struct ClientKeyExchange {
                     struct <0..2^16-1> {
                        uint16 length = 2;
                        uint8 bytes[1] = {0x30, 0x00};
                     } psk_identity;
                  } ;
               } ;
            } ;
            struct TLSPlaintext{
               uint8 type = 20; /* ChangeCipherSpec */
               uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
               uint16 length = 1;
               struct ChangeCipherSpec{
                  uint8 type = 1;    /* ChangeCipherSpec */
               };
            };
            struct TLSCiphertext {
               uint8 type = 22; /* Handshake */
               uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
               uint16 length = 32;
               struct GenericAEADCipher {
                  struct CCMNonceExplicit {
                     uint64 seq_num;
                  };
                  struct CCMCipherText { /* inferred from draft-mcgrew-tls-aes-ccm
*/
                     struct Handshake { /* Encrypted */
                        uint8 msg_type = 20; /* Finished */
                        uint24 length = 12;
                        struct Finished {
                           uint8 verify_data[12];
                        ;}
                     };
                     uint8 MAC[8]; /* Using AES_CCM_8 */
                  };
               };
            };
         };
         struct AVPPad {
         uint8 bytes[2];
      };
   };
};
```

6.5.3.16. TLS ChangeCipherSpec, TLS Finished (from the PAA to the PaC)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 134; /* 16H + (8H + 49P + 0Pd) */
   uint16 flags = 0x8000; /* Request */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id;
   uint32 seq_no = paa_seq_no + 4; /* Increment sequence number */
   struct PANAAVP {
      uint16 code = 2; /* EAP Payload */
      uint16 flags = 0;
```

```
        uint16 length = 49;
        uint16 rsvd = 0;
        struct EAPReqUnfrag {
            uint8 code = 1;
            uint8 identifier = idseq + 3;
            uint16 length = 49; /* inc. 6H + (5H + 1P) + (5H + 32P) */
            uint8 type = 13; /* EAP-TLS */
            uint8 flags = 0x00;
            struct TLSPlaintext{
                uint8 type = 20; /* ChangeCipherSpec */
                uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
                uint16 length = 1;
                struct ChangeCipherSpec{
                    uint8 type = 1;    /* ChangeCipherSpec */
                };
            };
            struct TLSCiphertext {
                uint8 type = 22; /* Handshake */
                uint8 version[2] = {0x03, 0x03}; /* TLS 1.2 */
                uint16 length = 32;
                struct GenericAEADCipher {
                    struct CCMNonceExplicit {
                        uint64 seq_num;
                    };
                    struct CCMCipherText { /* inferred from draft-mcgrew-tls-aes-ccm
*/
                        struct Handshake { /* Encrypted */
                            uint8 msg_type = 20; /* Finished */
                            uint24 length = 12;
                            struct Finished {
                                uint8 verify_data[12];
                            };
                        };
                        uint8 MAC[8]; /* Using AES_CCM_8 */
                    };
                };
            };
        };
    };
};
```

6.5.3.17. Final EAP response (from the PaC to the PAA)

```
struct PANA {
    uint16 rsvd = 0;
    uint16 length = 30; /* 16H + (8H + 6P + 2Pd) */
    uint16 flags = 0x0000; /* Answer */
    uint16 type = 2; /* PA */
    uint32 session_id = paa_session_id; /* Returned by PaC */
    uint32 seq_no = paa_seq_no + 4; /* Returned by PaC */
    struct PANAAVP {
        uint16 code = 2; /* EAP Payload */
        uint16 flags = 0;
        uint16 length = 6;
        uint16 rsvd = 0;
        struct EAPRspUnfrag {
            uint8 code = 2;
            uint8 identifier = idseq + 3; /* Corresponds to request */
            uint16 length = 6; /* inc. 6H + 0P */
            uint8 type = 13; /* EAP-TLS */
            uint8 flags = 0x00;
        };
        struct AVPPad {
```

```
      uint8 bytes[2];
    };
  };
};
```

6.5.3.18. PANA Complete, EAP Success (from the PAA to the PaC)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 128; /* 16H + (8H + 4P) + (8H + 4P) + (8H + 4P) + (8H + 4P) +
(8H + (12H + 18P + 2Pd) + (8H + 16P) */
   uint16 flags = 0xA000; /* Request, Complete */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id;
   uint32 seq_no = paa_seq_no + 5; /* Increment sequence number */
   struct PANAAVP {
      uint16 code = 7; /* Result code */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 result_code = 0; /* PANA_SUCCESS */
   };
   struct PANAAVP {
      uint16 code = 2; /* EAP Payload */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      struct EAPSuccess {
         uint8 code = 3;
         uint8 identifier = idseq + 4;
         uint16 length = 4; /* inc. 4H + 0P */
      };
   };
   struct PANAAVP {
      uint16 code = 4; /* Key ID */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 key_id = 0; /* Initial MSK */
   };
   struct PANAAVP {
      uint16 code = 8; /* Session Lifetime */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 sess_life = 0xFFFFFFFF; /* -1 = forever (136 years) */
   };
   struct PANAAVP {
      uint16 code = 13; /* Encrypted Encapsulation */
      uint16 flags = 0;
      uint16 length = 32;
      uint16 rsvd = 0;
      struct PANAAVP {
        uint16 code = 1; /* ZigBee Network Key */
        uint16 flags = 1; /* Vendor specific */
        uint16 length = 18;
        uint16 rsvd = 0;
        uint32 vendor_id = 37244; /* ZigBee Vendor ID */
      struct ZBNWKKEY {
         uint8 nwk_key[16];
         uint8 nwk_key_idx;
         uint8 auth_cntr;
      };
```

```
        struct AVPPad {
        uint8 bytes[2];
      };
     };
   };
   struct PANAAVP {
      uint16 code = 1; /* Auth */
      uint16 flags = 0;
      uint16 length = 16;
      uint16 rsvd = 0;
      uint8 auth[16]; /* Hash */
   };
};
```

6.5.3.19. PANA Complete (from the PaC to the PAA)

```
struct PANA {
   uint16 rsvd = 0;
   uint16 length = 54; /* 16H + (8H + 4P) + (8H + 16P) */
   uint16 flags = 0x2000; /* Answer, Complete */
   uint16 type = 2; /* PA */
   uint32 session_id = paa_session_id; /* Returned by PaC */
   uint32 seq_no = paa_seq_no + 5; /* Returned by PaC */
   struct PANAAVP {
      uint16 code = 4; /* Key ID */
      uint16 flags = 0;
      uint16 length = 4;
      uint16 rsvd = 0;
      uint32 key_id = 0; /* Initial MSK */
   };
   struct PANAAVP {
      uint16 code = 1; /* Auth */
      uint16 flags = 0;
      uint16 length = 16;
      uint16 rsvd = 0;
      uint8 auth[16]; /* Hash */
   };
};
```

6.6. Annex-2

This section describes changes to the specifications for each layer that are required for implementation for 920MHz PHY. The corresponding parameter and other values described above shall be overwritten with the values specified in this section.

6.6.1. Physical layer

For 920MHz PHY, the modulation scheme shall be specified to FSK and the data rate shall be set to 100kbit/s, which are specified in IEEE 802.15.4g-2012 [802.15.4], and other items shall be treated as options. A preamble length of at least 12 bytes is recommended in consideration of the reception using a diversity antenna.

The PSDU size shall be up to 254 bytes. While transmission and reception using CSM is specified in IEEE 802.15.4g-2012 [802.15.4], the use of CSM shall be optional in this specification. While IEEE 802.15.4g-2012 [802.15.4] specifies MR-FSK data whitening is optional, MR-FSK data whitening shall be used in this specification.

6.6.2. Data link layer

Since the PSDU size shall be up to 254 bytes, the 2-octet FCS shall be used, and the use of the 4-octet FCS shall be optional.

While IEEE 802.15.4g-2012 [802.15.4] specifies that multi-PHY management (MPM) is mandatory when 1% duty cycle is exceeded, MPM shall be optional in this specification.

6.6.3. Network layer

6.6.3.1. Multicast

While [EL] specifies that FF02:0:0:0:0:0:0:1 shall be used for the multicast address, the address shall be replaced with the following address:

Unicast address

FF02:0:0:0:0:0:0:1

FF03:0:0:0:0:0:0:1

FF05:0:0:0:0:0:0:1

FF03:0:0:0:0:0:0:2

FF05:0:0:0:0:0:0:2

If a multicast request is transmitted for a specification which requires a multicast response such as the property value notification service according to [EL], communication traffic increases as the number of terminals increases.

Since ZigBee IP assumes multihop communication, it may be assumed that multicast communication is required to be made to broader scope.

For this reason, it is desirable to set appropriate scope for the multicast destination address.

6.6.3.2. RPL attribute

The minimum value (MIN_RPL_INSTANCE_COUNT) for the RPL Instance shall be 1.

6.6.3.3. Transport

For ECHONET Lite [EL] application data communication, UDP packets shall be used for transmission and reception, and TCP packets shall be optional. The destination port number of UDP frames shall always be 3610 as described in [EL].

6.6.4. Application layer

For the application layer, ECHONET Lite [EL] shall be used. The nodes compliant with the specifications for this system shall support all required functions specified in [EL].

[EL] shall provide the following services:

- Detection of functional units (ECHONET objects) employed by the other nodes in the network
- Acquisition of parameters and statuses (ECHONET properties) the other nodes have
- Configuration of parameters and statuses for the other nodes
- Notification of parameters and statuses the local node has

6.7. Annex-3

This section clarifies the IEEE 802.15.4/4g functions that should be supported.

The "Status in IEEE standard" column indicates specifications in IEEE 802.15.4/4g. M means a mandatory function and O means an optional function. The "Use of system B" column indicates whether to use the relevant item in system B. Y means a required function, N means a function not required, and O means an optional function. O.x means that only one item of the same type is to be used.

6.7.1. Device specifications

The use specifications of the functions related to devices in IEEE 802.15.4/4e/4g are shown below.

Table 6-26: Functional device types

Number	Description	Reference section in standard	Status in IEEE standard	Use of system B
FD1	Parent device	[802.15.4] 5.1	O.1	O.1
FD2	Child device	[802.15.4] 5.1	O.1	O.1
FD3	Support of 64-bit address	[802.15.4] 5.2.1.1.6	M	Y
FD4	Short address assignment	[802.15.4] 5.1.3.1	FD1: M	FD1: Y
FD5	Support of short address	[802.15.4] 5.2.1.1.6	M	Y
FD8	15.4g-compatible device	[802.15.4g] 8.1	O.3	Y

6.7.2. Physical layer specifications

The use specifications of the functions related to the physical layer are shown below.

Table 6-27: PHY functions and PHY packets

Number	Description	Reference section in standard	Status in IEEE standard	Use of system B
PLF1	Energy detection	[802.15.4] 8.2.5	FD1: M	FD1: Y
PLF2	Link quality indication	[802.15.4] 8.2.6	M	Y
PLF3	Channel selection	[802.15.4] 8.1.2	M	Y
PLF4	Clear channel assessment	[802.15.4] 8.2.7	M	Y
PLF4.1	Determination of CCA with field intensity	[802.15.4] 8.2.7	O.2	Y
PLF4.2	Determination of CCA with carrier sense	[802.15.4] 8.2.7	O.2	N
PLF4.3	Concurrent use of 1 and 2	[802.15.4] 8.2.7	O.2	N
PLP1	PSDU size	[802.15.4g] 9.2	FD8: M	Up to about 255 bytes is recommended.

Table 6-28: Radio frequency (RF)

Number	Description	Reference section in standard	Status in IEEE standard	Use of system B
RF12	SUN PHYs			
RF12.1	MR-FSK	[802.15.4g] 16.1	FD8: M	Y
RF12.2	MR-OFDM	[802.15.4g] 16.2	FD8: O	N
RF12.3	MR-O-QPSK	[802.15.4g] 16.3	FD8: O	N
RF12.4	MR-FSK-Generic PHY	[802.15.4g] 8.1.2.7.2	RF12.1: O	N
RF12.5	Transmit and receive of extended beacons with shared signals	[802.15.4g] 8.1a	FD1, 8, MLF15: M	N
RF12.6	Selection of frequency used	[802.15.4g] 8.1	FD8: M	920MHz
RF13	SUN PHY operating modes			
RF13.4	50kbit/s and 100kbit/s supported when 920MHz is used	[802.15.4g] 16.1	FD8: M	Use 100kbit/s.
RF13.5	200kbit/s and 400kbit/s supported when 920MHz is used	[802.15.4g] 16.1	FD8: O	N
RF14	MR-FSK options	[802.15.4g]		
RF14.1	MR-FSK FEC	[802.15.4g] 16.1.2.4	O	N
RF14.2	MR-FSK interleaving	[802.15.4g] 16.1.2.5	O	N
RF14.3	MR-FSK data whitening (scrambling)	[802.15.4g] 16.1.3	O	Y
RF14.4	Data rate changed in packet units	[802.15.4g] 16.1.4	O	N

Table 6-29: PHY

Item	Use of system B	Remarks
Modulation scheme	GFSK	
Data rate	100kbit/s	
Transmission power	20 mW or less	
Frequency channel	Channels of Nos. 33 to 60 specified in ARIB with bundling of an odd channel and the next even channel	Channels of Nos. 33 to 38 are also used by systems with a transmission power of 250mW.
Occupied bandwidth	400kHz (with 2 channel bundling)	
Transmission preamble length	At least 12 bytes	

6.7.3. Data link layer specifications

The use specifications of the functions related to the data link layer are shown below.

Table 6-30: MAC sub-layer functions -1

Number	Description	Reference section in standard	Status in IEEE standard	Use of system B
MLF1	Transmission of data	[802.15.4] 6.3	M	Y
MLF1.1	Purge data	[802.15.4] 6.3.4, 6.3.5	FD1: M FD2: O	FD1: M FD2: O
MLF2	Reception of data	[802.15.4] 6.3	M	Y
MLF2.1	Receive processing control	[802.15.4] 5.1.6.5	FD1: M FD2: O	N
MLF2.2	Control of PHY receiver	[802.15.4] 6.2.9	O	N
MLF2.3	Timestamp	[802.15.4] 6.3.2	O	N
MLF3	Beacon management	[802.15.4] Clause 5	M	Y
MLF3.1	Transmit beacons	[802.15.4] Clause 5, 5.1.2.4	FD1: M FD2: O	FD1: Y FD2: O
MLF3.2	Receive beacons	[802.15.4] Clause 5, 6.2.4	M	Y
MLF4	Channel access	[802.15.4] Clause 5, 5.1.1	M	Y
MLF5	Guaranteed time slot management	[802.15.4] Clause 5, 6.2.6,	O	N
MLF5.1	Guaranteed time slot management	[802.15.4] Clause 5, 6.2.6,	O	N
MLF5.2	Guaranteed time slot management	[802.15.4] Clause 5, 6.2.6,	O	N
MLF6	Frame validation	[802.15.4] 6.3.3, 5.2, 5.1.6.2	M	Y

Table 6-31: MAC sub-layer functions -2

Number	Description	Reference section in standard	Status in IEEE standard	Use of system B
MLF7	Acknowledged frame delivery	[802.15.4] Clause 5, 6.3.3, 5.2.1.1.4, 5.1.6.4	M	Y
MLF8	Association	[802.15.4] Clause 5, 6.2.2, 6.2.3, 5.1.3	M	N*1
MLF9	Security	[802.15.4] Clause 7	M	Y
MLF9.1	Unsecured mode	[802.15.4] Clause 7	M	Y
MLF9.2	Secured mode	[802.15.4] Clause 7	O	Y
MLF9.2.1	Data encryption	[802.15.4] Clause 7	O.4	Y

MLF9.2.2	Frame integrity	[802.15.4] Clause 7	O.4	Y
MLF10.1	Energy detection scanning	[802.15.4] 5.1.2.1, 5.1.2.1.1	FD1: M FD2: O	FD1: Y FD2: O
MLF10.2	Active scanning	[802.15.4] 5.1.2.1.2	FD1: M FD2: O	Y
MLF10.3	Passive scanning	[802.15.4] 5.1.2.1.2	M	Y
MLF10.4	Orphan scanning	[802.15.4] 5.1.2.1, 5.1.2.1.3	M	O*2
MLF11	Superframe structure control	[802.15.4] 5.1.1.1	FD1: O	N
MLF12	Support of superframe structure	[802.15.4] 5.1.1.1	O	N
MLF13	Store one transaction	[802.15.4] 5.1.5	FD1: M	Y
MLF15	Multiple PHY management	[802.15.4g] 5.1.9	FD8: M	N

*1: Not used since done in an upper layer.

*2: May not be used since optional in an upper layer.

Table 6-32: MAC frames

Number	Description	Reference section in standard	Status in IEEE standard		Use of system B
			Transmit	Receive	
MF1	Beacon	[802.15.4] 5.2.2.1	FD1: M	M	Y
MF2	Data	[802.15.4] 5.2.2.2	M	M	Y
MF3	ACK	[802.15.4] 5.2.2.3	M	M	Y
MF4	Command	[802.15.4] 5.2.2.4	M	M	Y
MF4.1	Association request	[802.15.4] 5.2.2.4, 5.3.1	M	FD1: M	N*1
MF4.2	Association response	[802.15.4] 5.2.2.4, 5.3.2	FD1: M	M	N*1
MF4.3	Disassociation notification	[802.15.4] 5.2.2.4, 5.3.3	M	M	N*1
MF4.4	Data request	[802.15.4] 5.2.2.4, 5.3.4	M	FD1: M	Y
MF4.5	PAN ID conflict notification	[802.15.4] 5.2.2.4, 5.3.5	M	FD1: M	N
MF4.6	Orphaned device notification	[802.15.4] 5.2.2.4, 5.3.6	M	FD1: M	O*2
MF4.7	Beacon request	[802.15.4] 5.2.2.4, 5.3.7	FD1: M	FD1: M	Y*3
MF4.8	Parent device reconfiguration	[802.15.4] 5.2.2.4, 5.3.8	FD1: M	M	Y
MF4.9	GTS request	[802.15.4] 5.2.2.4, 5.3.9	MLF5: O	MLF5: O	N
MF5	32-bit FCS	[802.15.4g] 5.2.1.9	FD6: M	FD6: M	Y*4

*1: Not used since done in an upper layer.

*2: May not be used since optional in an upper layer.

*3: Can also be used for a child device (clarifies an FD2 specification not included in the reference standard).

*4: Use 16-bit FCS when the PSDU size does not exceed 255 octets.

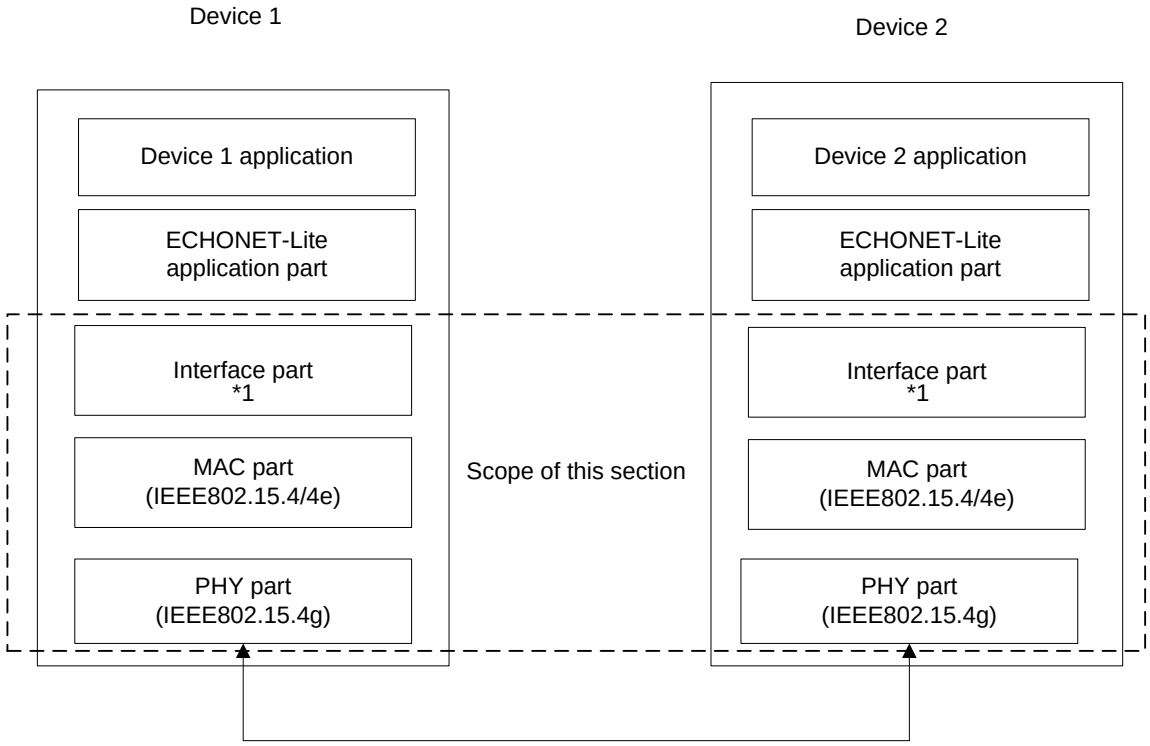
7. System C

7.1. Overview

This chapter defines the physical layer part, data link layer part, and interface part (provided as an option) that are required for ECHONET Lite communication between a coordinator and host only using IEEE802.15.4/4e/4g (Sections 7.3 to 7.9) and specifies the recommended specification for configuring a single-hop network using EHONET Lite (Section 7.10).

The physical and data link layer parts are composed of selected functions specified in the IEEE802.15.4/4e/4g standard. The interface part is used to connect the ECHONET Lite application part directly to the data link layer and physical layer since the following case is assumed: The addressing architecture specified in the ECHONET Lite application part differs from that specified in the data link layer part. The part transmits transmission data from the ECHONET Lite application part to the destination device using the data link and physical layers and transmits reception data from the destination device to the ECHONET Lite application part. **Figure 7-1** shows the location of each part. **Figure 7-2** shows the layer structure.

.In this chapter, "M" means a mandatory function in the standards [802.15.4], [802.15.4e], and [802.15.4g], "O" means an optional function, "Y" means a function required for operating ECHONET Lite, and "N" means a function not required. Specifications and procedures for certification and interoperability tests are provided by [Wi-SUN-PHY], [Wi-SUN-MAC], [Wi-SUN-IF], [Wi-SUN-CTEST], and [Wi-SUN-ITEST].

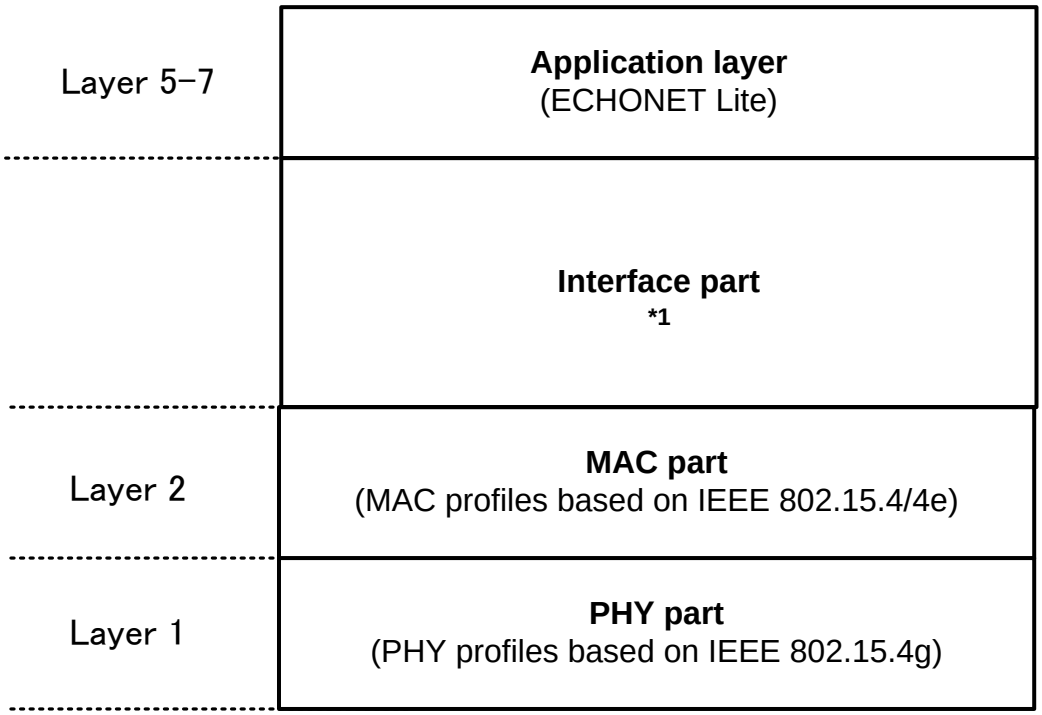


(*1: Not required in case addressing architectures are the same between the ECHONET Lite application part and data link layer part.)

Figure 7-1 Scope defined by this chapter

7.2. Protocol stack

The protocol stack for a node specified for this system is shown in **Figure 7-2**.



(*1: Not required in case addressing architectures are the same between the ECHONET Lite application part and data link layer part.)

Figure 7-2 Layer structure defined by this chapter

The physical layer provides the following service as far as it is used in this system:

- Up-to-2047-octet PSDU exchange (Note that the system recommends 255 octets or less as described below.)

The data link (MAC) layer provides the following services as far as it is used in this system:

- Discovery of an IEEE802.15.4 PAN in radio propagation range
- Support of low-energy hosts that can change its status between sleep and active states
- Security functions that include encryption, manipulation detection, and replay attack protection (Note that key management is not performed by this layer.)

The application layer provides the following services:

- Detection of functional units (ECHONET objects) employed by the other nodes in the network
- Acquisition of parameters and statuses (ECHONET properties) the other nodes have
- Configuration of parameters and statuses for the other nodes
- Notification of parameters and statuses the local node has

7.3. Physical layer part

See Section 5.3.

7.4. Data link layer (MAC layer) part

See Section 5.4.

7.5. Interface part

7.5.1. Overview

The interface part shall be implemented between the ECHONET Lite application part and physical layer part/data link layer part and provide a function to communicate between them, assuming that the addressing architecture specified in the ECHONET Lite application part differs from that specified in the data link layer part. This interface can improve frame utilization efficiency by reducing overhead when IP is used.

7.5.2. Requirements

(1) The interface part shall specify unique destination addresses when used. It also shall configure an ECHONET Interface header by specifying the source address and Interface Type. In this case, the Interface Type shall be 0xEC00.

(2) The interface part shall know the address configuration used in the MAC part in advance. The address configuration needs to be an EUI-64-bit address.

(3) The interface part must convert the unique destination address specified in the interface part according to the addressing architecture used in the MAC part and transmit it to the MAC part.

(4) When the MAC address transmitted from the ECHONET Lite application part is a multicast MAC address, the interface part shall instruct the MAC part to do broadcast transmission.

7.6. Application layer

As the application layer, ECHONET Lite [EL] shall be used and all required functions specified in [EL] shall be supported.

7.7. Security

There are the following two ways for ensuring security in the non-IP mode. Either way shall be implemented as a requirement.

- Data encryption in the IEEE 802.15.4 MAC part (required when the interface part is not used)
- Data encryption in the interface part

AES-CCM and/or AES-GCM shall be implemented as the encryption scheme for data encryption in the interface part [EL], [CMAC], [AES-CCM], [AES-GCM]. To use AES-CCM/GCM, MIC (message integrity code) or AAD (Additional Authenticated Data) must be used. For AES-CCM data encryption in the IEEE 802.15.4 MAC part, the MIC must be contained in the IEEE 802.15.4 MAC frame described in document [1]. On the other hand, for data encryption in the interface part, the MIC shall be contained in the security header described in Section 4.4.6.5.

7.8. Device ID

As an optional function in the non-IP mode, the device ID assigned to each ECHONET Lite-compatible device may be used. This device ID may be used during MAC address initialization and other processes. In this case, there are two types of payload handled: Information payload and setting payload. Information payload is used for ECHONET Lite data exchange and setting payload is used for device ID exchange.

7.9. Frame formats

This section describes frame formats used for this system. The frame format differs depending on whether the interface part is used. To identify a frame format in a receiving node, The specification separately provided for coexistence between systems is used.

7.9.1. When the interface part is used

7.9.1.1. When data encryption in the MAC part is used

Sample frame formatting procedures for using data encryption in the MAC part are shown in **Figure 7-3** to **Figure 7-5**. In these figures, the destination and source MAC addresses differ between the ECHONET Interface header and IEEE 802.15.4 MAC header. These two addresses can be omitted.

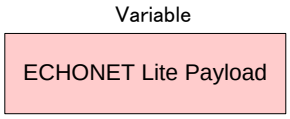


Figure 7-3: ECHONET Lite payload

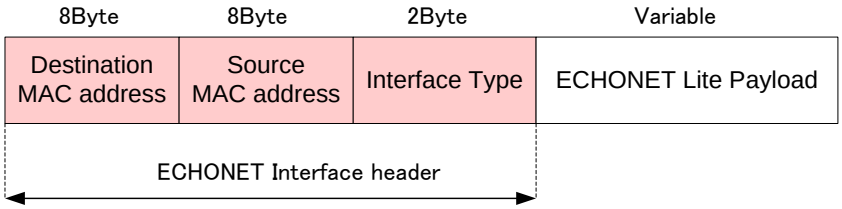


Figure 7-4: Frame configured in the interface part

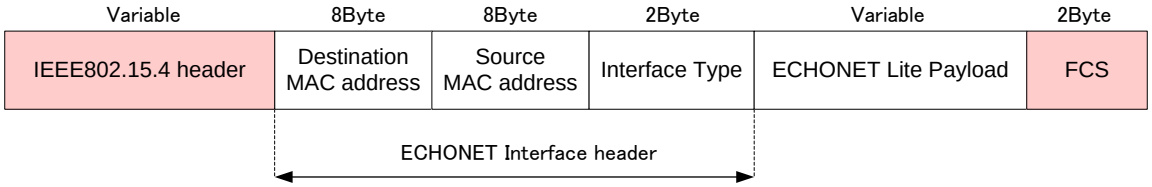


Figure 7-5: IEEE 802.15.4 frame configured in the MAC part

7.9.1.2. When data encryption in the interface part is used

Sample frame formatting procedure for using data encryption in the interface part are shown in **Figure 7-6** to **Figure 7-8**. In these figures, the destination and source MAC addresses differ between the ECHONET Interface header and IEEE 802.15.4 MAC header. These two addresses can be omitted.

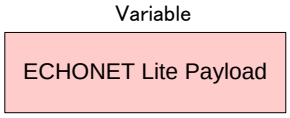


Figure 7-6: ECHONET Lite payload

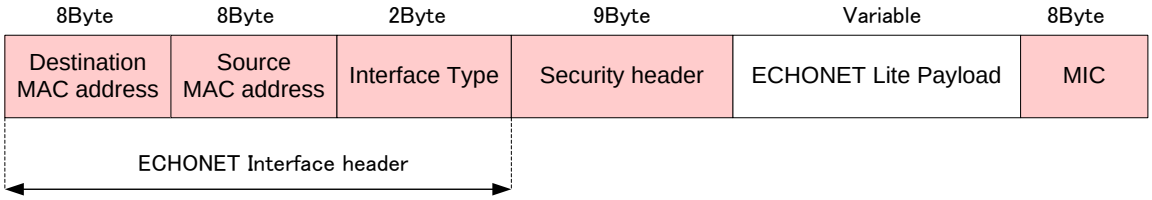


Figure 7-7: Frame configured in the interface part

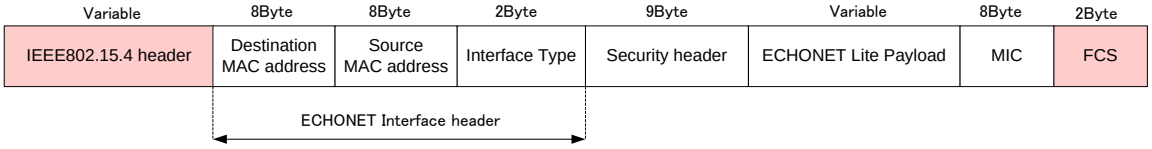


Figure 7-8: IEEE 802.15.4 frame configured in the MAC part

7.9.1.3. When the device ID option and data encryption in the interface part are used

This section gives figures that show a procedure for converting information payload from the ECHONET Lite application to the MAC part frame when the device ID option and data encryption in the interface part are used. In these figures, the destination and source MAC addresses differ between the ECHONET Interface header and IEEE 802.15.4 MAC header. These two addresses can be omitted.

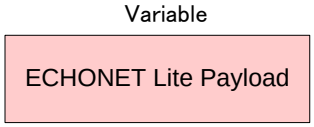


Figure 7-9: ECHONET Lite payload

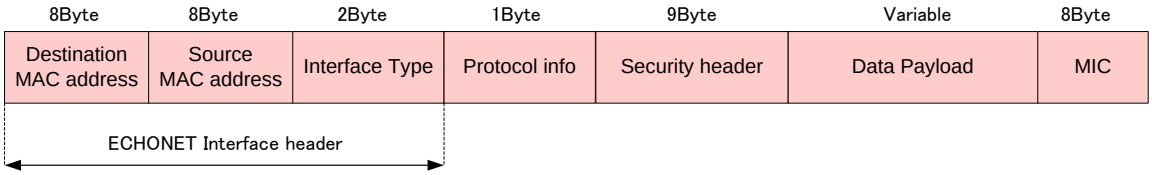


Figure 7-10: Frame configured in the interface part

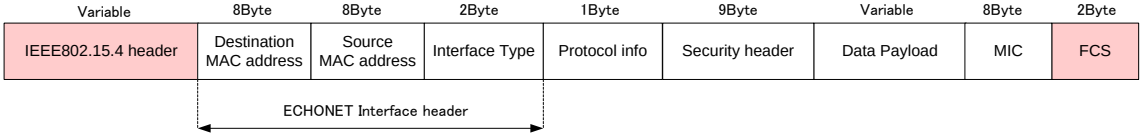


Figure 7-11: IEEE 802.15.4 frame configured in the MAC part

7.9.1.4. Frame elements

7.9.1.4.1. ECHONET Lite payload

ECHONET Lite information payload generated in the ECHONET Lite application part

7.9.1.4.2. ECHONET Interface header

The ECHONET Interface header is generated uniquely in the interface part. **Figure 7-12** shows the structure.

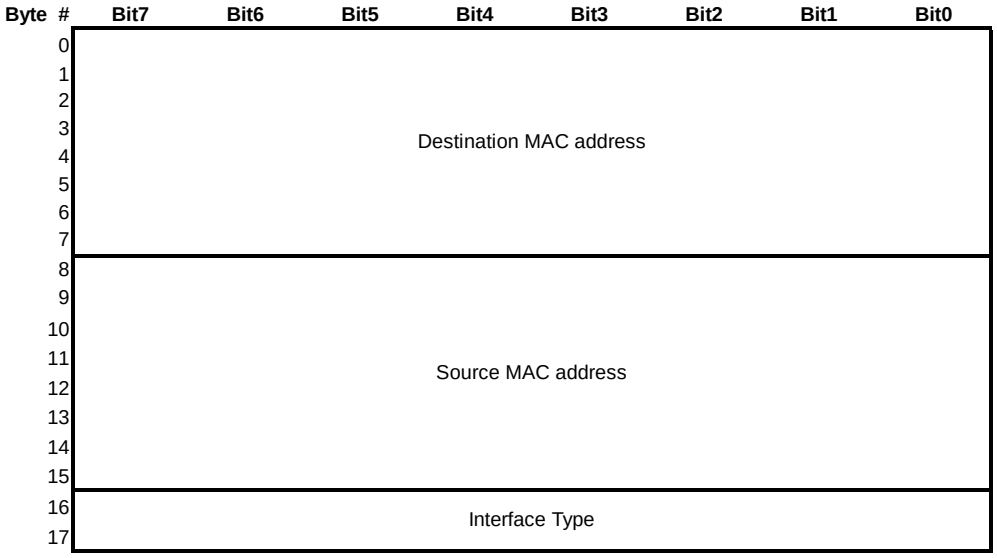


Figure 7-12: ECHONET Interface header format

(a) Destination address

Destination address determined in collaboration between the ECHONET Lite application part and interface part

(b) Source address

Source MAC address. This address is configured based on the address configuration in the MAC part by the interface part.

(c) Interface Type

0xEC00: Interface Type for ECHONET Lite

7.9.1.4.3. IEEE 802.15.4 header

Header for transmission and reception that is generated by the MAC part

7.9.1.4.4. FCS (Frame check sequence)

Frame check sequence generated in the MAC part

7.9.1.4.5. Security header

The security header is used to define information related to encryption for transmission data. **Figure 7-13** shows the format.

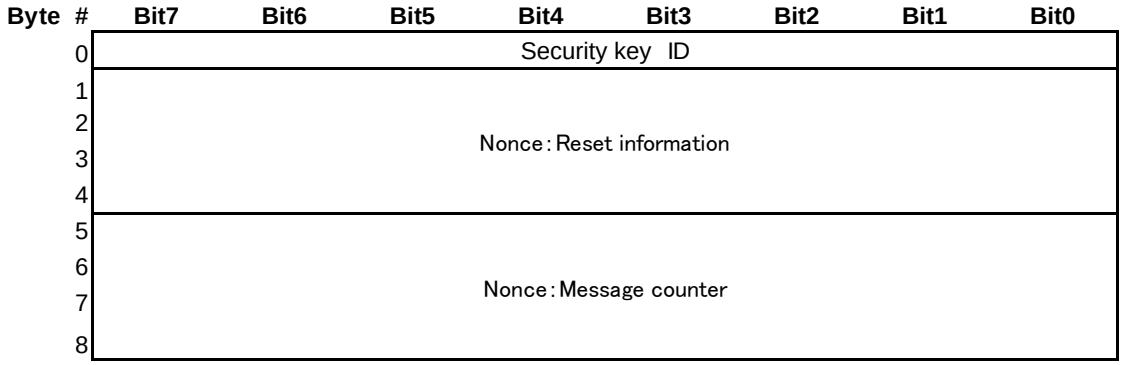


Figure 7-13: Security header format

(a) Security key ID

Identifier corresponding to the encryption key used

(b) Nonce (byte# 1-8)

For nonce, a unique value is configured for each transmission data and encrypted together with data. A nonce consists of the following elements:

Reset information (byte# 1-4): Specifies an incremental value used for each reset of the device.

Message counter (byte# 5-8): Counter for the number of messages transmitted

7.9.1.4.6. MIC (message integrity code)

Code used for AES-CCM encryption

7.9.1.4.7. Protocol info

Protocol info indicates the protocol type of data to be transmitted, which is used when a unique device ID is defined. **Figure 7-14** shows the format.

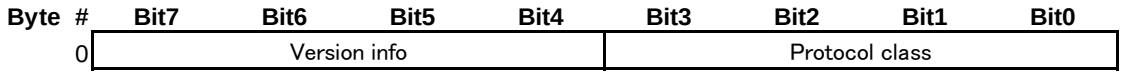


Figure 7-14: Format of protocol info

(a) Version info: 4 bits long. Up to 16 versions can be specified.

(b) Protocol class: Used for identifying setting payload and information payload.

0000: Information payload, 0001: Setting payload

7.9.1.4.8. Data payload

Data payload carries either information payload or setting payload containing a device ID. Information payload or setting payload is selected according to the protocol class value. The format is shown below.

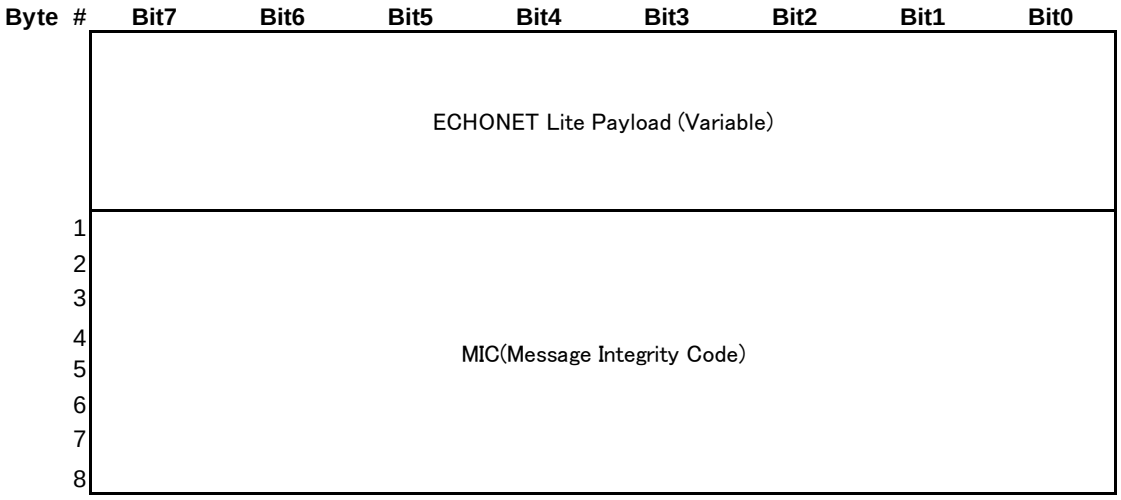


Figure 7-15: Information payload format

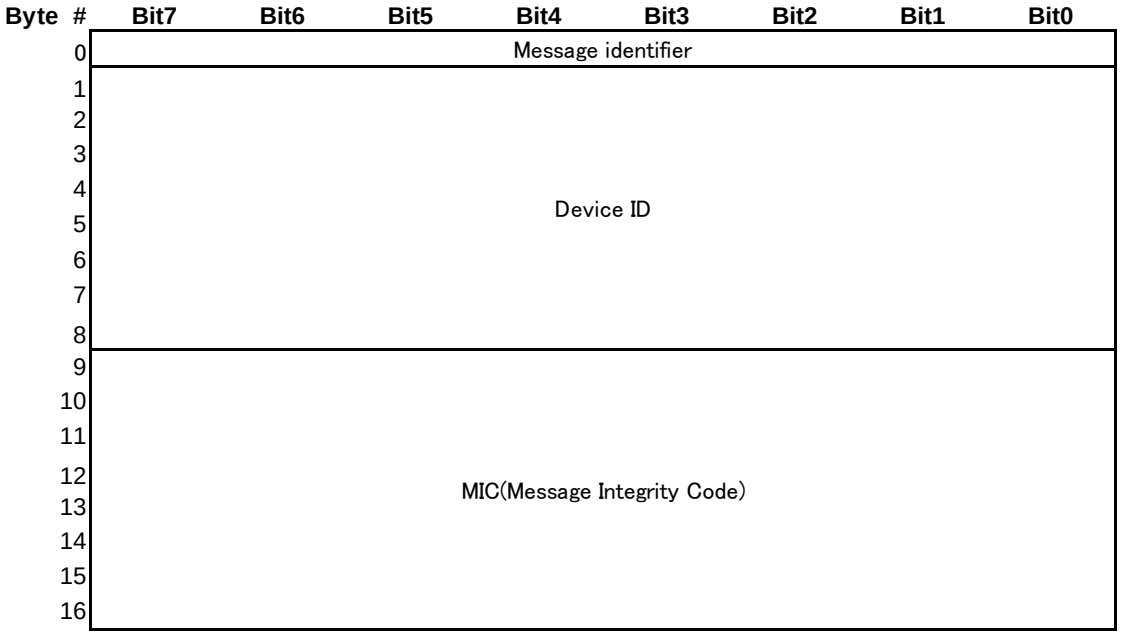


Figure 7-16: Setting payload format

(a) Message identifier: Used for indicating a setting request or response.

00000000: Setting request

00000001: Setting response

7.9.2. When the interface part is not used

When the ECHONET Lite application part directly handles IEEE 802.15.4 MAC addresses, the interface part is unnecessary. Sample frame formats used when the interface part is not used are shown in **Figure 7-17** and **Figure 7-18**. When the interface part is not used, the IEEE 802.15.4 header is located just before ECHONET Lite Payload.

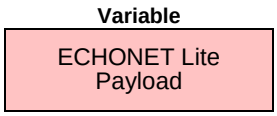


Figure 7-17: ECHONET Lite payload

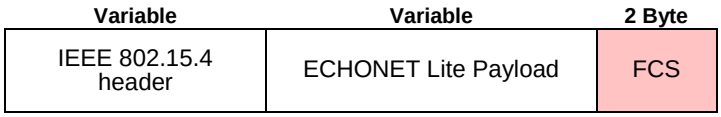


Figure 7-18: IEEE 802.15.4 frame configured in the MAC frame

7.10. Recommended specification for configuring a single-hop network

7.10.1. Overview

This section describes the recommended specification for constructing a single-hop network using ECHONET Lite in system C. Other specifications are not excluded as far as system C specification is conformed.

Nodes based on the specification in this section construct a single-hop network where a coordinator is centered. And, with assuming a gateway connection provided by the application layer as the connection measure to external networks, a closed network is assumed inside this system. On those assumptions, the indoor network construction using ECHONET Lite provides expandability as well as feasibility.

7.10.2. Construction of a new network

Once turned on, a coordinator constructs a new network compliant with this system specification. The network construction is conducted by successive steps of (1) data link layer configuration and (2) security configuration. An overview of the network construction procedure is shown in **Figure 7-19**.

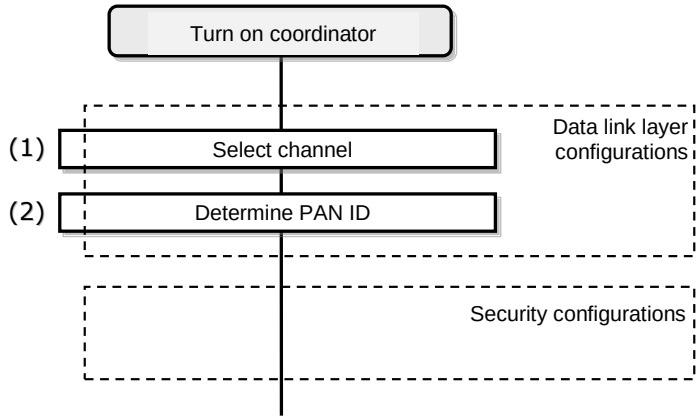


Figure 7-19: Overview of network construction procedure

7.10.2.1. Data link layer configurations

Once turned on, a coordinator constructs an IEEE 802.15.4 PAN. A detailed procedure for PAN construction is as follows.

The coordinator first selects a channel to use. The channel selection is conducted via ED scanning or active scanning. In the selection, a channel with less interference to the other systems is more preferable. (Step 1)

Finally, the coordinator selects a PAN ID that is not occupied by any PAN on the channel selected in Step 1, and defines it as the PAN ID to be used in the network the coordinator manages. For this system, the following procedure is not specified: How the coordinator selects a PAN ID that is not occupied by any PAN on the channel selected in Step 1 as the PAN ID of the local network. (Step 2)

After the previous steps, the coordinator completes the PAN construction using the determined radio channel and PAN ID.

7.10.2.2. Security configurations

The coordinator conducts security configurations following data link layer configurations. Security technologies employed in the constructed network should be selected according to the application requirements. This system specification does not describe a specific procedure for security configurations conducted by the coordinator.

7.10.3. Joining in a network

Once turned on, a new host tries to join the existing network compliant with this system. The joining procedure by the host includes (1) data link layer configuration and (2) security configuration just in a same manner as the network construction by a coordinator. An overview of the procedure for joining the existing network by a new host is shown in **Figure 7-20**.

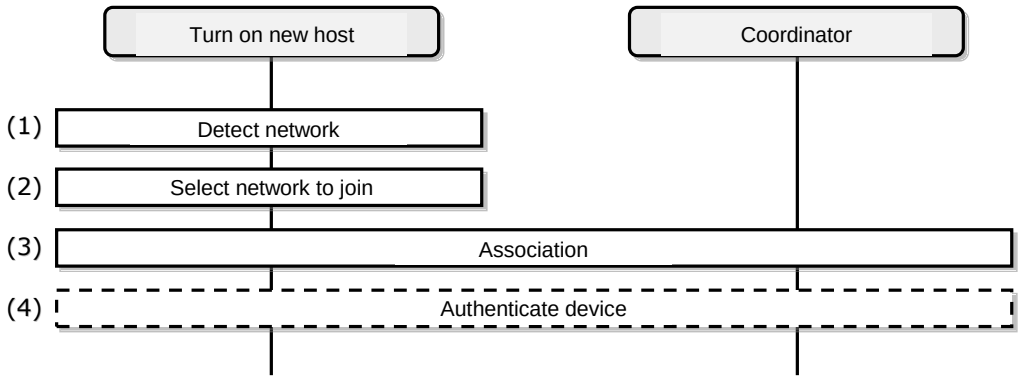


Figure 7-20: Overview of network joining procedure

7.10.3.1. Data link layer configurations

Once turned on, first, a new host detects an existing IEEE 802.15.4 PAN around it. The PAN detection procedure is as follows: The new host transmits a beacon request command message specified in [802.15.4] to all available radio channels specified in [802.15.4] and [T108]. A coordinator that receives the message transmits a beacon frame as a response. The new host receives the beacon. Moreover, the new host can recognize the radio channel and PAN ID employed by the coordinator, as a result of this procedure. (Step 1)

If only one PAN is detected in Step 1, the host proceeds to the next step for that PAN. If multiple PANs are detected, the host selects one of them and proceeds to the next step. Which PAN the host selects depends on the implementation. (Step 2)

The new host conducts association specified in IEEE 802.15.4 for the PAN selected in Step 2. (Step 3)

If the new host fails to join the selected PAN as the result of association for the PAN, for example, due to connection rejection by the coordinator, the host is recommended to retry the joining procedure from Step 1 or 2. In the retry procedure, the host should select a network other than that the host fails to join.

7.10.3.2. Security configurations

After the completion of joining the IEEE802.15.4 PAN, the new host conducts security configurations with the coordinator. Since security technologies employed in the constructed network are out of scope of this system specification, this system specification does not describe a specific procedure for security configurations conducted with network joining.

7.10.4. Specifications for the device/physical layer/MAC layer to implement the recommended specification

See Section 5.8.4.