**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |
| --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
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| Re: | Resolution of LLDN-related comment in IEEE 802.15.4 REVc (Sponsor Ballot SB01).  |
| Abstract | This document provides the text for Low Latency Deterministic Networks (LLDN) to be included in IEEE 802.15.4 REVc. It is the submission for the resolution of the LLDN comments to IEEE 802.15.4 REVc related to the LLDN mode (comments in Sponsor Ballot SB01). The text is adapted to version DF5 of the IEEE 802.15.4 REVc document. The text follows the guidelines from the July 2015 Waikoloa meeting.This document is the text for the resolution of comments in IEEE 802.15.4 REVc related to Low Latency Deterministic Networks (LLDN) and based on the results of the July 2015 Waikoloa meeting, so that the LLDN mode stays in REVc of the IEEE 802.15.4 standard. |
| Purpose | Specification of Low Latency Deterministic Networks of IEEE 802.15.4e to be kept in REVc of IEEE 802.15.4. |
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**Note: This text of 15-15/616r3 is the submission for resolving the LLDN comments of the first Sponsor Ballot on IEEE 802.15.4 REVc.**

This document provides the submission with the text of Low Latency Deterministic Networks (LLDN) to be included in IEEE 802.15.4 REVc. It is the text for resolutions of comments in the IEEE 802.15.4 REVc Sponsor Ballot SB01 related to the LLDN mode. It follows the structure agreed to at the Waikoloa Meeting (July 2015) of IEEE 802.15.4.

The text is adapted to version DF5 of the IEEE 802.15.4 REVc document.

The purpose of this document is to keep the specification of Low Latency Deterministic Networks of IEEE 802.15.4e in the REVc of IEEE 802.15.4. The final document will be the submission in response to the LLDN comments of SB01 on IEEE 802.15.4 REVc.

Changes compared to 15-15/616r2

* Changes according to SC Maintence Conference Call from August 10, 2015

Changes compared to 15-15/616r1

* Review of figures, all figures as emf (except tabular figures such as frame formats)
* macLLDN 🡪 macLldn
* extended text on LLDN configuration state
* text on reception of LLDN beacons
* text on initialization of LLDN configuration sequence number
* text on LLDN extensions to MAC data service
* extended list of LLDN MAC PIB attributes

To Editor: Insert in alphabetical order the following definitions in “3.1 Definitions”:

**downlink:** Data communication from the personal area network (PAN) coordinator to the PAN device.

**low latency deterministic network (LLDN):** A personal area network (PAN) organized as a star network with an LLDN superframe structure and using LLDN frames.

**low latency deterministic network (LLDN) device:** A device in an LLDN that is associated to an LLDN PAN coordinator.

**low latency deterministic network (LLDN) frame:** frame with specific frame type transmitted in LLDN superframes.

**low latency deterministic network (LLDN) slot owner:** An LLDN device that is assigned exclusive access rights at the beginning of a timeslot in an LLDN.

**low latency deterministic network (LLDN) superframe:** periodically repeating structure of timeslots used for low latency transmissions.

**uplink:** data communication from the personal area network (PAN) device to the PAN coordinator.

***To Editor: Insert in “3.2 Acronyms and abbreviations” the following abbreviations and acronyms in alphabetical order:***

CTS clear to send

GACK group acknowledgment

LL low latency

LLD low latency deterministic

LLDN low latency deterministic network

RTS request to send

To Editor: Insert in “5.2 Special Application Spaces” the following clause 5.2.5a before clause “5.2.6 Medical body area network (MBAN) services”

### 5.2.5a Low Latency Deterministic Networks (LLDN)

Low Latency Deterministic Networks (LLDN) are defined for industrial applications with low latency transmission. LLDNs operate in a star topology with an LLDN superframe. LLDNs use LLDN frames. They can be distinguished by a specific Frame Type, so that the operation of LLDNs is independent of any other MAC mode operation. The detailed specification of LLDN is provided in Annex G.

To Editor: Insert in “5.5.1 Star network formation” the following paragraph as new 2nd paragraph:

A low latency deterministic network (LLDN) operates in a star topology. More information on the star topology of LLDNs is given in ”Applications of IEEE Std 802.15.4” [B2].

To Editor: Insert the following paragraph as 4th item in the 2nd paragraph of “5.7.1 Superframe structure”

* + - * + LLDN superframe structure described in based on LLDN Beacons defined in .

To Editor: Insert the following clause 5.7.1.2a after clause “5.7.1.2 Slotframes”

5.7.1.2a LLDN Superframe structure based on LLDN Beacons

LLDN PANs use the LLDN superframe structure as described in more detail in . The LLDN superframe is divided into an LLDN Beacon slot, 0 or 2 LLDN Management timeslots, and a number of LLDN base timeslots of equal length and arranged in uplink LLDN timeslots and bidirectional LLDN timeslots as shown in Figure 10a.



Figure 10a—General LLDN Superframe

The LLDN timeslots are assigned to the LLDN devices in the network. Adjacent LLDN timeslots may be concatenated to larger LLDN timeslots.

Insert in clause 5.7.4 “Access methods” the following text as 5th item in the list in the second paragraph

* simplified slotted CSMA-CA used in LLDNs, as described in .

To Editor: Insert in “6.2.1 Superframe structure” after the first paragraph the following text:

For LLDN, an LLDN superframe structure with LLDN Beacons is required, as described in .

To Editor: Change 7.2.1 as indicated:

7.2.1 Frame Control field

The Frame Control field for frames other than the LLDN frame, Multipurpose frame, Fragment frame, and Extended frame shall be formatted as illustrated in Figure 87. The Frame Control fields for the Multipurpose frame, Extended frame, and LLDN frame are specified in 7.3.5, 7.3.6, and G.4.1 respectively.

To Editor: Change Table 5 as indicated:

**7.2.1.1 Frame Type field**

**Table 5—Values of the Frame Type field**

|  |  |
| --- | --- |
| **Frame type value b2 b1 b0** | **Description** |
| 000 | Beacon |
| 001 | Data |
| 010 | Acknowledgment |
| 011 | MAC command |
| 100 | LLDN |
| 101 | Multipurpose |
| 110 | Fragment or Frak1 |
| 111 | Extended |

***To Editor: Change the third paragraph of 7.2.1.8 and Table 7 as follows:***

**7.2.1.8 Destination Addressing Mode field**

If the Frame Type field does not specify an LLDN frame or Multipurpose frame, and the Source Addressing and Destination Addressing Mode fields are set to zero, and the PAN ID Compression field is set to one, the Frame Version field (described in 7.2.1.9) shall be set to 0b10.

Table 7—Valid values of the Destination Addressing Mode and Source Addressing Mode fields

|  |  |
| --- | --- |
| **Addressing mode value b1 b0** | **Description** |
| 00 | PAN Identifier and Address fields are not present. |
| 01 | Address field contains a simple address (8-bit), used in LLDN only. |
| 10 | Address field contains a short address (16 bit). |
| 11 | Address field contains an extended address (64 bit). |

***To Editor: Change in 7.2.1.9 the Table 8 and add note as follows:***

**7.2.1.9 Frame Version field**

**Table 8—Frame Version field values**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frame type** | **Frame Version 0b00** | **Frame Version 0b01** | **Frame Version 0b10** | **Frame Version 0b11** |
| Beacon | IEEE Std 802.15.4-2003 | IEEE Std 802.15.4-2006 | IEEE Std 802.15.4 | Reserved |
| Data | IEEE Std 802.15.4-2003 | IEEE Std 802.15.4-2006 | IEEE Std 802.15.4 | Reserved |
| Acknowledgment | IEEE Std 802.15.4-2003 | IEEE Std 802.15.4-2006 | IEEE Std 802.15.4 | Reserved |
| MAC Command | IEEE Std 802.15.4-2003 | IEEE Std 802.15.4-2006 | IEEE Std 802.15.4 | Reserved |
|  |  |  |  |  |
| Multipurpose | IEEE Std 802.15.4 | Reserved | Reserved | Reserve |
|  |  |
|  |  |

Note: The Frame Version field has a different format in LLDN frames as described in G.4.1. The Frame Version field is not present in Fragment frames and Extended frames.

To Editor: Insert before “7.2 General MAC frame format” the following text as 3rd (text) paragraph:

**7.2 General MAC frame format**

If the Frame Type field indicates an LLDN frame, then the frame format shall be formatted as illustrated in .

***Note to Editor: The LowLatencyNetworkInformation IE (0x20) of “5.2.4.2 Header Information Elements” (15.4e) has been omitted.***

***Note to Editor: The Group ACK IE (0x1f) of “5.2.4.2 Header Information Elements” (15.4e) and described in 5.2.4.12 “Group ACK IE” has been omitted.***

***To Editor: Change in 7.5 the first paragraph and Table 50 as follows. Not all lines are given in Table 50:***

**7.5 MAC commands**

The MAC commands are listed in Table 50 along with their associated command identifier. All FFDs shall be capable of transmitting and receiving all MAC command with Comamnd Identifier field of values 0x01–0x08, with the exception of the GTS Request command, while the requirements for an RFD are indicated by an “X” in the table. An FFD supporting one of TRLE, LLDN, DSME, RIT or DBS options shall support the associated MAC commands in the range 0x0d−0x1e as identified by the associated functional group prefix, e.g., “DSME ” for the DSME option.

 **Table** **50—MAC commands**

|  |  |  |  |
| --- | --- | --- | --- |
| **Command identifier** | **Command name** | **RFD** | **Subclause** |
| **TX** | **RX** |
| 0x0b | [TRLE Management Response command](file:///D%3A%5CDATA%5Cmchn1520%5CDesktopPC%5CCT-LT%5CIEEE-802.15.4-2015%5CP802.15.4-REVc-DF3.docx#_bookmark1671) | X | X | [F.5.2.2](file:///D%3A%5CDATA%5Cmchn1520%5CDesktopPC%5CCT-LT%5CIEEE-802.15.4-2015%5CP802.15.4-REVc-DF3.docx#_bookmark1671) |
| 0x0c | Reserved |  |  |  |
| 0x0d | LLDN-Discover response | X |  | G.5.1 |
| 0x0e | LLDN-Configuration status | X |  | G.5.2 |
| 0x0f | LLDN-Configuration request |  | X | G.5.3 |
| 0x10 | LLDN-CTS shared group |  | X | G.5.4 |
| 0x11 | LLDN-Request To Send (RTS) | X | X | G.5.5 |
| 0x12 | LLDN-Clear to send (CTS) |  | X | G.5.6 |
| 0x13 | [DSME Association Request command](file:///D%3A%5CDATA%5Cmchn1520%5CDesktopPC%5CCT-LT%5CIEEE-802.15.4-2015%5CP802.15.4-REVc-DF3.docx#_bookmark457) | X |  | [7.5.12](file:///D%3A%5CDATA%5Cmchn1520%5CDesktopPC%5CCT-LT%5CIEEE-802.15.4-2015%5CP802.15.4-REVc-DF3.docx#_bookmark457) |

***To Editor: Insert the following paragraph as 3rd paragraph of “8.2.1 Primitives supported by the MLME-SAP interface”***

When the optional LLDN mode is implemented (i.e., *macLldnCapable* = TRUE), the primitives listed in shall be implemented.

***To Editor: Insert in “8.4.2.1 General MAC PIB attributes for functional organization“ in „Table 134—General MAC PIB attributes for functional organization“***

***between lines „macTschCapable“ and „macDsmeCapable“ the following line:***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *macLldnCapable* | Boolean | TRUE or FALSE | If TRUE, the device is capable of functionality specific to LLDNs | ⎯ |

***between lines „macTschEnabled“ and „macDsmeEnabled“ the following line:***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *macLldnEnabled* | Boolean | TRUE or FALSE | If TRUE, the device is using functionality specific to LLDNs | ⎯ |

***To Editor: Insert the following subclause as new subclause “8.4.2.5a LLDN specific MAC PIB attributes” before clause “8.4.2.6 MAC performance metrics specific MAC PIB attributes“***

8.4.2.5a LLDN specific MAC PIB attributes

Subclause 8.4.2.1 applies and additional attributes and LLDN-specific settings are required as described in and in .

***To Editor: Insert the following rows in Table D.6 as MLF 16a between ”MLF15 TSCH Capability“ and „MLF16 DSME capabilities“:***

**D.7.3.1 MAC sublayer functions**

**Table D.6—MAC sublayer functions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item number** | **Item description** | **Reference** | **Status** | **Support** |
| **N/A** | **Yes** | **No** |
| MLF16a | LLDN Capability | , , , , ,  | O |  |  |  |
| MLF16a.1 | LLDN-MAC Management Services |  | MLF16a:M |  |  |  |
| MLF16a.3 | LLDN Channel Access |  | MLF16a:M |  |  |  |
| MLF16a.4 | LLDN Superframe structure |  | MLF16a:M |  |  |  |
| MLF16a.5 | LLDN Transmission States |  | MLF16a:M |  |  |  |

***To Editor: Insert the following rows in Table D.7:***

**D.7.3.2 MAC frames**

**Table D.7—MAC frames**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item Number** | **Item description** | **Reference** | **Transmitter** | **Receiver** |
| **Status** | **SupportN/A****Yes****No** | **Status** | **Support****N/A****Yes****No** |
| MF3.4 | LLDN |  | MLF16a:M,FD1║FD2:M |  | MLF16a:M,FD1║FD2:M |  |
|  |  |  |  |  |  |  |
| MF4.21a | LLDN Discover Response command, |  | MLF16a::M |  |  |  |
| MF4.21b | LLDN Configuration Status command, |  | MLF16a::M |  |  |  |
| MF4.21c | LLDN Configuration Request command, |  | MLF16a:M |  |  |  |
| MF4.21d | LLDN Clear To Send (CTS) Shared Group command, |  | MLF16a:M |  |  |  |
| MF4.21e | LLDN Request To Send (RTS) command,  |  | MLF16a:O |  |  |  |
| MF4.21f | LLDN Clear To Send (CTS) command |  | MLF16a:O |  |  |  |

***To Editor: Insert the following text as Annex G “G. Low Latency Deterministic Networks (LLDN)” after Annex F “Time-slot relaying based link extension (TRLE)“***

# Annex G

(normative)

# Low Latency Deterministic Networks (LLDN)

Low Latency Deterministic Networks (LLDN) are defined for industrial applications with low latency transmission (see ”Applications of IEEE Std 802.15.4” [B2]). LLDNs operate in a star topology with an LLDN superframe (see ). LLDNs use LLDN frames (see ). They can be distinguished by a specific Frame Type “LLDN”, so that the operation of LLDNs is independent of any other MAC mode operation.

During the LLDN configuration, the LLDN utilizes different LLDN transmission states (see ). Data is transmitted during LLDN Online state in LLDN timeslots, which are assigned to LLDN devices.

An LLDN shall be only operated in an unsecured mode, because it uses simple addressing (8-bit).

## LLDN superframe structure

### **LLDN superframe general structure**

LLDN PANs (i.e., *macLldnEnabled* is TRUE) use the LLDN superframe structure. The superframe is divided into an LLDN beacon slot, 0 or 2 LLDN management timeslots, and a number of LLDN base timeslots of equal length and arranged in uplink LLDN timeslots and bidirectional LLDN timeslots as shown in .



Figure .—LLDN superframe general structure

The first timeslot of each LLDN superframe contains an LLDN Beacon frame. The LLDN Beacon frame is used for synchronization with the LLDN superframe structure. It is also used for re-synchronization of LLDN devices that, for instance, went into power save or sleep mode.

The LLDN beacon timeslot may be followed by two LLDN management timeslots, one for downlink transmission and one for uplink transmission.

The LLDN base timeslots S1 to Am are assigned to the LLDN devices in the LLD network. The LLDN time slots are divided into uplink LLDN timeslots S1 to Sn, followed by bidirectional LLDN timeslots A1 to Am. A few first uplink LLDN timeslots may be assigned as retransmission LLDN timeslots.

As shown in , there is a specific order in the meaning or usage of the LLDN timeslots in an LLDN superframe, as follows:

* LLDN Beacon Timeslot (G.1.3): always present.
* LLDN Management Timeslots (G.1.4): one LLDN Management timeslot downlink, one LLDN Management timeslot uplink, presence is configurable in *macLldnMgmtTs* during the LLDN Configuration state, presence and length are indicated in the LLDN Beacon ().
* Uplink LLDN timeslots for LLDN devices (G.1.6): *macLldnNumUplinkTs* LLDN base timeslots uplink (unidirectional communication), *macLldnNumRetransmitTs* LLDN base timeslots at the beginning of the uplink LLDN base timeslots can be reserved for retransmissions according to the LLDN Group Acknowledgement field contained in the LLDN Beacon as described in 7.3.4a.2 and 6.10a.4.
* Bidirectional LLDN timeslots for LLDN devices (G.1.7): *macLldnNumBidirectionalTs* LLDN base timeslots uplink/downlink (bidirectional communication).

*macLldnNumRetransmitTs* shall be less than or equal to *macLldnNumUplinkTs* / 2, *macLldnNumUplinkTs* + *macLldnNumBidirectionalTs* shall be equal to *macLldnNumTs*.

### **Structure of LLDN superframe with separate LLDN GACK**

It is also possible to use a separate LLDN Group Acknowledgement (GACK) frame as described in in order to facilitate retransmissions of failed LLDN transmissions in the uplink LLDN timeslots within the same LLDN superframe. The use of a separate LLDN GACK is configurable during LLDN configuration mode. If the use of a separate LLDN GACK is configured, the structure of the superframe is as depicted in .



Figure .—LLDN superframe with separate LLDN GACK

Descriptions of the LLDN configuration parameters for the LLDN superframe with a separate LLDN GACK differ from the general structure of the LLDN superframe (G.1.1) only for the Uplink LLDN Timeslots:

* Uplink LLDN Timeslots: *macLldnNumUplinkTs* denotes the total number of LLDN base timeslots available for uplink (unidirectional) communication. Typically, one LLDN base timeslot is allocated to each LLDN device. In this case, *macLldnNumUplinkTs – macLldnNumRetransmitTs* - 1 denotes the number of LLDN devices, *macLldnNumRetransmitTs* denotes the number of LLDN base timeslots allocated for LLDN devices that failed their original transmissions prior to the LLDN GACK and need to retransmit their message and denotes the number of LLDN devices that are allowed to retransmit. One timeslot is allocated for each retransmitting LLDN device.
* LLDN GACK timeslot: One of *macLldnNumUplinkTs*. It contains a bitmap of (*macLldnNumUplinkTs* – *macLldnNumRetransmitTs* – 1) bits to indicate successful and failed uplink LLDN transmissions in the same order as the uplink LLDN transmissions.

The LLDN Beacon frame in the LLDN mode always carries the LLDN GACK bitmap (see ) even if a separate LLDN GACK frame is used. The LLDN GACK bitmap is used for acknowledging the successful retransmissions in the retransmission LLDN timeslots since some of the retransmitted LLDN frames may fail.

### **LLDN Beacon timeslot**

The LLDN beacon timeslot is reserved for the LLDN PAN coordinator to indicate the start of an LLDN superframe with the transmission of an LLDN beacon. The LLDN beacon is used to (re-)synchronize the LLDN devices and to indicate the current LLDN transmission mode (G.4.2). The LLDN beacon also contains acknowledgments for the data transmitted in the previous LLDN superframe in the LLDN GACK field of the LLDN beacon ().

The LLDN beacon timeslot is available in every LLDN superframe.

### **LLDN Management timeslots**

The first portion of an LLDN superframe after the LLDN beacon timeslot is formed by the LLDN management timeslots, i.e., the downlink and uplink LLDN management timeslots.

The downlink direction is defined from the LLDN PAN coordinator to the LLDN device. The uplink direction is defined from the LLDN device to the LLDN Coordinator.

LLDN Management timeslots provide a mechanism for bidirectional transmission of LLDN management data in downlink and uplink direction. Downlink and uplink LLDN management timeslots are provided in equal number in an LLDN superframe. There are two LLDN management timeslots per LLDN superframe: first the downlink LLDN management timeslot, second the uplink LLDN management timeslot.

The length of the LLDN management timeslots is defined in the LLDN Beacon as described in .

LLDN Management timeslots are implemented as shared group access timeslots.

Downlink and uplink LLDN Management timeslots are used in the LLDN Discovery state and the LLDN Configuration state and are optional in the LLDN Online state. These LLDN states are described in G.3.1.

### **LLDN timeslots**

After the LLDN management timeslots, LLDN timeslots for the transmission of data are contained in an LLDN superframe. They are assigned to specific LLDN devices of the LLD network.

Each LLDN timeslot may have assigned a so-called LLDN slot owner. The LLDN slot owner has access privileges in the LLDN timeslot (dedicated LLDN timeslot).

There is no explicit addressing necessary inside the LLDN timeslots provided that there is exactly one LLDN device assigned to an LLDN timeslot as per . The determination of the sender LLDN device is achieved through the number (index) of the LLDN base timeslot.

More than one LLDN device can be assigned to an LLDN timeslot (shared group LLDN timeslot). The LLDN devices use a contention-based access method (LLDN simplified CSMA-CA as specified in G.2.3) and a simple addressing scheme with 8-bit addresses, macSimpleAddress, in shared group timeslots.

### **Uplink LLDN timeslots**

Uplink LLDN timeslots allow for unidirectional data communication (uplink from LLDN device to LLDN PAN coordinator) only. *macLldnNumUplinkTs* specifies the number of uplink LLDN base timeslots.

The first *macLldnNumRetransmitTs* of the *macLldnNumUplinkTs* uplink LLDN base timeslots are dedicated LLDN base timeslots for retransmissions of failed uplink LLDN transmission attempts in LLDN base timeslots of the previous LLDN superframe. The dynamic assignment of LLDN devices to retransmission LLDN base timeslots is described in G.3.1.4.

### **Bidirectional timeslots**

Bidirectional LLDN timeslots allow for bidirectional communication between the LLDN PAN coordinator and the LLDN devices. The direction of the communication is indicated in the LLDN beacon as described in 7.3.4a.2. Bidirectional LLDN timeslots are used for the transmission of device data to the LLDN PAN coordinator (uplink) as well as of data from the LLDN PAN coordinator to the LLDN device (downlink). *macLldnNumBidirectionalTs* specifies the number of bidirectional LLDN base timeslots.

## LLDN channel access

### **LLDN timeslots**

The structure of the LLDN superframe is defined by means of LLDN base timeslots of equal length, as described in G.1.1. The length of an LLDN base timeslot is defined by the LLDN Base Tiemslot Size field of the LLDN Beacon as described in .

Multiple adjacent LLDN base timeslots of the uplink LLDN base timeslots or the bidirectional LLDN base timeslots may be concatenated to LLDN timeslots in order to provide longer transmission times to some LLDN devices.

An LLDN timeslots is dedicated to a single LLDN device (dedicated LLDN timeslot), shared among a group of LLDN devices (shared group LLDN timeslot), or a combination of both as specified in G.2.2.

### **Channel access within LLDN timeslots**

Each LLDN timeslot is described by four time attributes as illustrated in and described in .



Figure G.3—Time attributes of LLDN timeslots

Table G.1—Time attributes of LLDN timeslots

|  |  |
| --- | --- |
| **Attribute** | **Description** |
| *tSlotStart* | Starting time of LLDN timeslot |
| *tSlotTxOwner* | End time of privileged access by LLDN device that owns the LLDN timeslot (dedicated LLDN device) |
| *tSlotTxGW* | If LLDN timeslot is unused, LLDN PAN coordinator may use the LLDN timeslot |
| *tSlotEnd* | End time of LLDN timeslot |

From *tSlotStart* till *tSlotTxOwner*, the LLDN device that owns the LLDN timeslot, the LLDN slot owner or dedicated LLDN device, has exclusive access to the LLDN timeslot.

From *tSlotTxOwner* till *tSlotTxGW*, any LLDN device other than the LLDN PAN coordinator may use the LLDN timeslot for data transmission with the LLDN simplified CSMA-CA access scheme as described in G.2.3, if the LLDN timeslot is not used by the LLDN slot owner. If the LLDN timeslot is not used by the LLDN slot owner, the LLDN PAN coordinator shall indicate this by broadcasting an LLDN CTS Shared Group frame (). To reduce the chances of collisions from other LLDN devices trying to use this LLDN timeslot, an LLDN device may send an LLDN Request To Send (RTS) frame () and wait for the receipt of the corresponding LLDN CTS frame () from the LLDN PAN coordinator that identifies this LLDN device, before it transmits its data with the LLDN simplified CSMA-CA access scheme as described in G.2.3.

From *tSlotTxGW* till *tSlotEnd*, the LLDN PAN coordinator may use the LLDN timeslot, if the LLDN timeslot is still unused.

*tSlotStart ≤ tSlotOwner ≤ tSlotTxGw ≤ tSlotEnd* with *tSlotStart < tSlotEnd*.

Dedicated LLDN timeslots are reserved for a single LLDN device (LLDN slot owner). This is achieved by setting *tSlotTxOwner* and *tSlotTxGW* to *tSlotEnd*. A dedicated LLDN timeslot allows the transmission of exactly one data frame. Dedicated LLDN timeslots are only used during LLDN Online state as described in G.3.1.4.

Shared group LLDN timeslots with contention-based access for every allowed LLDN device are achieved by setting *tSlotTxOwner* to *tSlotStart*.

### **LLDN simplified CSMA-CA**

The LLDN simplified CSMA-CA algorithm is used during LLDN Management timeslots (G.1.4) and Shared Group LLDN timeslots (G.2.1) in LLDNs.

The LLDN simplified CSMA-CA is a slotted CSMA-CA mechanism. In principle, it follows the slotted version of the CSMA-CA algorithm as described in 6.2.5.1, but uses different (default) values for some parameters as given in in .

 illustrates the steps of the LLDN simplified CSMA-CA algorithm. If the algorithm ends in “Success,” the MAC is allowed to begin transmission of the frame. Otherwise, the algorithm terminates with a channel access failure.



Figure .—LLDN simplified CSMA-CA algorithm

*NB* is the number of backoffs during the current transmission and shall be initialized to zero before each new transmission attempt. *CW* is the contention window length. *CW*0 shall be initialized to two before each transmission attempt and reset to *CW*0 each time the channel is assessed to be busy. *BE* is the backoff exponent, which is related to how many backoff periods a device shall wait before attempting to assess a channel. Note that if *macMinBe* is set to zero, collision avoidance will be disabled during the first iteration of this algorithm. The LLDN-specific default values for *macMinBE*, *macMaxBE*, and *macMaxCSMABackoffs* are given in in .

The MAC sublayer shall ensure that, after the random backoff, the remaining CSMA-CA operations can be undertaken and the entire transaction can be transmitted before the end of the LLDN timeslot.

The backoff slots of *aUnitBackoffPeriod* symbols are aligned with the start of the LLDN beacon transmission in the LLDN Management timeslots and with *tSlotTxOwner* in shared group LLDN timeslots (see G.2.1).

Each time a device wishes to transmit data frames with CSMA-CA at the appropriate places, it locates the boundary of the next backoff slot and then waits for a random number of backoff slots. If the channel is busy, following this random backoff, the device waits for another random number of backoff slots before trying to access the channel again. If the channel is idle, the device begins transmitting on the next available backoff slot boundary. Acknowledgment and beacon frames are sent without using a CSMA-CA mechanism.

## LLDN MAC functional description

### **LLDN transmission states**

#### **General**

The transitions between the different LLDN transmission states are illustrated in Figure G.5.



Figure .—Transitions between LLDN transmission states

The LLDN Discovery state is the first step during LLD network setup: the new LLDN devices are discovered, they are configured in the second step, the LLDN Configuration state. After the successful completion of the LLDN Configuration state, the LLD network can go into the LLDN Online state. Data and readings from the LLDN devices can only be transmitted during LLDN Online state. In order to reconfigure an LLD network, the LLDN Configuration state can be started again.

#### **LLDN Discovery state**

The LLDN Discovery state is the first step during LLD network setup or for the addition of new LLDN devices to an existing LLD network.

In the LLDN Discovery state, the LLDN superframe contains only the LLDN Beacon timeslot () for the LLDN Beacon described in G.4.2 and two LLDN Management timeslots, one downlink and one uplink ().

A new LLDN device scans the different channels until it detects an LLDN PAN coordinator sending LLDN Beacons that indicate LLDN Discovery state.

If a new LLDN device received an LLDN Beacon indicating LLDN Discovery state, it attempts to access the medium in the uplink LLDN Management timeslot in accordance with in order to send an LLDN Discover Response frame to the LLDN PAN coordinator. The LLDN Discover Response frame is described in . The LLDN Discover Response frame contains the current configuration of the LLDN device. The new LLDN device shall repeat sending the LLDN Discover Response frame until it receives an LLDN Acknowledgment frame for it or the LLDN Discovery state is stopped by the LLDN PAN coordinator. The LLDN Acknowledgment frame is described in .

The LLDN PAN coordinator changes from the LLDN Discovery state to the LLDN Configuration state if it did not receive any LLDN Discover Response frames within *macLldnDiscoveryModeTimeout* seconds.

 illustrates the LLDN Discovery state.



Figure G.6—LLDN Discovery state message sequence

#### **LLDN Configuration state**

The LLDN Configuration state is the second step during LLD network setup. It is also used for LLDN reconfiguration.

In the LLDN Configuration state, the LLDN superframe contains only the LLDN Beacon timeslot () for the LLDN Beacon described in and two LLDN Management timeslots, one downlink and one uplink ().

If an LLDN device received an LLDN Beacon indicating LLDN Configuration state, it tries to get access to the transmission medium in the uplink LLDN Management timeslot in order to send an LLDN Configuration Status frame to the LLDN PAN coordinator. The LLDN Configuration Status frame is described in . The LLDN Configuration Status frame contains the current configuration of the LLDN device. The new LLDN device shall repeat sending the LLDN Configuration Status frame until it receives an LLDN Configuration Request frame for it or the LLDN Configuration state is stopped by the LLDN PAN coordinator. The LLDN Configuration Request frame is described in . The LLDN Configuration Request frame contains the new LLDN configuration for the receiving LLDN device. After successfully receiving the LLDN Configuration Request frame, the LLDN device sends an LLDN Acknowledgment frame to the LLDN PAN coordinator. The LLDN Acknowledgment frame is described in . The LLDN device stores the received current LLDN configuration including the LLDN PAN coordinator ID and the LLDN Configuration Sequence Number. The LLDN device may be capable of storing more than one LLDN configuration including LLDN PAN Coordinator ID and LLDN Configuration Sequence Number.

 illustrates the LLDN Configuration state.



Figure G.7—LLDN Configuration state message sequence

#### **LLDN Online state**

User data is only sent during LLDN Online state. The LLDN superframe starts with an LLDN Beacon in the LLDN Beacon timeslot and is followed by several LLDN timeslots. The LLDN devices can send their data during the LLDN timeslots assigned to them during the LLDN Configuration state. The different types of LLDN timeslots are described in , and the access in LLDN timeslots is described in .

The existence and length of LLDN Management timeslots in the LLDN Online state are contained in the LLDN Configuration Request frame and are indicated in the LLDN Beacon as described in .

The successful reception of data frames by the LLDN PAN coordinator is acknowledged in the LLDN Group Acknowledgment bitmap of the LLDN Beacon frame of the next LLDN superframe described in or in a separate LLDN Data Group Acknowledgment frame depicted in Figure G.20 in . Reception of data frames is acknowledged for both uplink LLDN timeslots and bidirectional LLDN timeslots if the LLDN transmission direction is uplink. illustrates an example of the LLDN Online state for uplink transmissions. In this example, the network has three dedicated LLDN timeslots, and LLDN device 2 is assigned to LLDN timeslot 2.



Figure .—LLDN Online state message sequence for LLDN devices (uplink)

If retransmission LLDN timeslots are configured (i.e., *macLldnNumRetransmitTs* > 0), the retransmission LLDN timeslots are assigned to the LLDN slot owners of the first *macLldnNumRetransmitTs* LLDN base timeslots with the corresponding bit in the LLDN Group Acknowledgment bitmap set to zero. Each LLDN device shall execute the algorithm as illustrated in in order to determine its retransmission LLDN timeslot. The LLDN PAN coordinator has to execute a similar algorithm in order to determine the LLDN senders of the data frames in the retransmission LLDN timeslots.



Figure .—Retransmission LLDN timeslot algorithm

Ack[i] represents the uplink success and maps to the bit b(i1) in the LLDN Group Acknowledgment bitmap as illustrated in Figure G.17 in . Assuming that the LLDN device has been assigned to uplink LLDN timeslot s, Ack[s] represents the uplink success of that LLDN device.

If the data transmission of the LLDN device has failed and has not been acknowledged, that is, ack[s] is zero (i.e., false), the LLDN device determines the number of failed LLDN transmissions in previous timeslots of the same LLDN superframe excluding retransmission LLDN timeslots. This number of failed LLDN transmissions, NFT, is the number of ack[i] equal to 0 (i.e., false) with (*macLldnNumRetransmitTs*+1) i (s1).

An LLDN retransmission is possible if the number of failed LLDN transmissions NFT is less than *macLldnNumRetransmitTs*. The LLDN device retransmits its data in retransmission LLDN timeslot (NFT+1).

If the number of failed LLDN transmissions NFT is equal or greater than *macLldnNumRetransmitTs*, an LLDN retransmission is not possible.

The successful reception of data frames by LLDN devices assigned to bidirectional LLDN timeslots (LLDN transmission direction is downlink) is acknowledged by an explicit LLDN Acknowledgment frame by the corresponding LLDN devices in the following LLDN superframe. This means that after setting the LLDN Transmission Direction bit in the LLDN Beacon described in to downlink and sending a data frame to one or more LLDN devices, the LLDN PAN coordinator shall set the LLDN Transmission Direction bit to uplink in the directly following LLDN superframe. LLDN devices assigned to bidirectional LLDN timeslots that have successfully received a data frame from the LLDN PAN coordinator during the previous LLDN superframe shall send an LLDN Acknowledgment frame to the LLDN PAN coordinator. LLDN devices that did not receive a data frame from the LLDN PAN coordinator may send data frames to the LLDN PAN coordinator during this LLDN superframe with LLDN Transmission Direction bit set to uplink.

Figure G.10 illustrates the LLDN Online state with LLDN devices assigned to bidirectional LLDN timeslots. In Figure G.10, the LLD network has three dedicated bidirectional LLDN timeslots, and LLDN device 2 is assigned to LLDN timeslot 2.



Figure .—LLDN Online state message sequence for LLDN devices (bidirectional)

### **LLDN Data Transfer Model**

#### **LLDN data transfer to an LLDN PAN coordinator**

When an LLDN device wishes to transfer data to an LLDN PAN coordinator in an LLDN, it first listens for the LLDN Beacon. When the LLDN Beacon is found, the LLDN device synchronizes to the LLDN superframe structure. At its assigned LLDN timeslot, the LLDN device transmits its data frame to the LLDN PAN coordinator. If the LLDN device transmits its data frame in a dedicated LLDN timeslot or as LLDN slot owner of a shared group LLDN timeslot, the data frame is transmitted without using CSMA-CA. If the LLDN device transmits its data frame in a shared group LLDN timeslot and is not the LLDN slot owner, the data frame is transmitted using slotted LLDN simplified CSMA-CA as described in . The LLDN PAN coordinator may acknowledge the successful reception of the data by transmitting an optional LLDN Acknowledgment frame (G.4.4). Successful LLDN data transmissions in dedicated LLDN timeslots or by the LLDN slot owner are acknowledged by the LLDN PAN coordinator with an LLDN Group Acknowledgment either in the next LLDN beacon (G.4.2) or as a separate LLDN Group Acknowledgment (GACK) frame if configured. This sequence is summarized in Figure G.11.



Figure .—Message sequence for data transfer to LLDN PAN coordinator

The LLDN Device transmits its data in the LLDN timeslots assigned to it during the LLDN configuration by the LLDN PAN coordinator.

The LLDN configuration (uplink LLDN timeslot or bidirectional LLDN timeslot) and the LLDN Transmission Direction bit in the LLDN Beacon (transmission direction in bidirectional LLDN timeslots) define transmitter and receiver of the LLDN Data frame.

If the LLDN device is the LLDN slot onwer of the assigned LLDN timeslot (dedicated LLDN timeslot), the LLDN device sends its data in an LLDN Data frame. The LLDN configuration, which is defined and distributed by the LLDN PAN coordinator and identified by the Network ID field and the Configuration Sequence Number field of the LLDN Beacon, specifies the assigned LLDN devices and LLDN slot owner for each LLDN timeslot. Based on the index of the LLDN base timeslot and the LLDN configuration, the LLDN PAN coordinator determines the sender of the LLDN Data frame.

If the LLDN device is not the LLDN slot owner of the assigned LLDN timeslot (shared group LLDN timeslot), the LLDN device sends its data in Data frames using simple addresses.

#### **LLDN data transfer from an LLDN PAN coordinator**

In LLD networks, a data transfer from an LLDN PAN coordinator is only possible in the *macLldnNumBidirectionalTs* timeslots described in and if the LLDN Transmission Direction field in the LLDN Flags field of the LLDN beacon indicates downlink direction.

When the LLDN PAN coordinator wishes to transfer data to an LLDN device assigned to a bidirectional LLDN timeslot in an LLDN, it indicates in the LLDN Beacon that the LLDN transmission direction is downlink. At the appropriate time, the LLDN PAN coordinator transmits its data frame to the LLDN device without using CSMA-CA. The LLDN device may acknowledge the successful reception of the data by transmitting an LLDN Acknowledgment frame to the LLDN PAN coordinator in the same LLDN timeslot of the next LLDN superframe. In order to do so, the LLDN transmission direction has to be uplink in that LLDN superframe. This sequence is summarized in Figure G.12.



Figure .—Message sequence for data transfer from LLDN PAN coordinator

The LLDN PAN coordinator transmits data to LLDN devices only in bidirectional LLDN timeslots with LLDN transmission direction set to downlink. If the LLDN PAN coordinator uses LLDN Data frames, only the LLDN slot owner for this LLDN timeslot, as defined by the current LLDN configuration, will accept the transmitted LLDN Data frame. In order to send data to LLDN device assigned to an LLDN timeslot but not the LLDN slot owner, the LLDN PAN coordinator sends its data in Data frames using simple addresses.

###  **LLDN Acknowledgment**

LLDNs use several methods for the acknowledgment of LLDN data transmissions. The timings of these mechanisms are defined by the LLDN superframe structure of the LLDN. The transmission of an LLDN Acknowledgment frame in response to an LLDN Data frame in an LLDN shall commence in the same bidirectional LLDN timeslot in the next LLDN superframe. The LLDN Acknowledgment frame shall only be used with bidirectional LLDN timeslots.

### **Reception of LLDN Beacons**

LLDN devices track the LLDN Beacon of their LLDN PAN coordinator in order to synchronize to the LLDN superframe.

When an LLDN device receives an LLDN Beacon, it compares the LLDN PAN coordinator ID and the LLDN configuration sequence number contained in the corresponding fields of the received LLDN Beacon with the LLDN PAN coordinator ID and LLDN configuration sequence number in its stored current LLDN configuration. If both, LLDN PAN coordinator ID and LLDN configuration sequence number are the same, the LLDN device uses its current LLDN configuration. If either LLDN PAN coordinator ID or LLDN configuration sequence number are not the same, the LLDN device checks its stored LLDN configurations whether an LLDN configuration is available that corresponds to the received LLDN PAN coordinator ID and LLDN configuration sequence number. If this is the case, it uses this LLDN configuration

## Low Latency Deterministic Network (LLDN) frame format

### **General LLDN frame format**

The general LLDN frame shall be formatted as illustrated in .

|  |  |  |
| --- | --- | --- |
| **Octets: 1** | **variable** | **2** |
| LLDN Frame Control | LLDN Frame Payload | FCS |
| MHR | MAC payload | MFR |

Figure G.13—General LLDN frame format

The order of the fields of the LLDN frame shall conform to the order of the general MAC frame as illustrated in Figure 86 in 7.2.

Four LLDN frame subtypes are defined: LLDN Beacon, LLDN Data, LLDN Acknowledgment, and LLDN MAC Command. These LLDN frame subtypes are specified in , , , and , respectively.

The LLDN Frame Control field contains information defining the frame subtype of the LLDN frame. The LLDN Frame Control field shall be formatted as illustrated in .

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits: 0–2** | **3** | **4** | **4** | **6–7** |
| Frame Type | Reserved | LLDNFrame Version | LLDNACK Request | LLDNFrame Subtype |

Figure G.14—Format of the LLDN Frame Control field (LLDN frame)

NOTE 1—The LLDN frame will be rejected by devices compliant to IEEE Std 802.15.4-2011 since the Frame Type value is listed as “reserved” by IEEE Std 802.15.4-2011. The position of the Frame Type should not be changed in future versions of the protocol.

The Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5 in 7.2.1.1.

NOTE 2—The Frame Type field corresponds to the Frame Type field of the general MAC frame format in 7.2 in meaning and position. The frame type for LLDN frames allows efficient recognition of LLDN frames with an LLDN Frame Control field of 1 octet, but allows the usage of all other MAC frames within the LLDN superframe structure.

Bit 3 of the LLDN Frame Control field is reserved and shall be set to zero. This field is reserved for future use.

The LLDN Frame Version field specifies the LLDN version number corresponding to the frame. This field shall be set to zero to indicate a frame compatible with IEEE Std 802.15.4. A value of one shall be reserved for future use.

The LLDN ACK Request field specifies whether an acknowledgment is required from the recipient device on receipt of a data or MAC command frame. If this field is set to one, the recipient device shall send an acknowledgment frame only if, upon reception, the frame passes the third level of filtering as described in 6.7.2 If this field is set to zero, the recipient device shall not send an acknowledgment frame.

The LLDN Frame Subtype field indicates the subtype of the LLDN frame. It shall be set to one of the values listed in .

Table G.2—Values of LLDN Frame Subtype field (LLDN frame)

|  |  |
| --- | --- |
| **Frame Subtype value b7 b6** | **Description** |
| 00 | LLDN Beacon |
| 01 | LLDN Data |
| 10 | LLDN Acknowledgment |
| 11 | LLDN MAC Command |

The LLDN Frame Payload field has a variable length and contains information specific to individual subframe types of an LLDN frame.

### **LLDN Beacon frame format**

The LLDN Beacon frame is sent during the beacon slot in every LLDN superframe. The LLDN Beacon frame shall be formatted as illustrated in .

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Octets: 1** | **1** | **1** | **1** | **1** | **0/1** | **variable** | **2** |
| LLDN Frame Control | LLDN Beacon Flags | LLDN PAN coordinator ID field | LLDN Configuration Sequence Number | Max LLDN Data Size | Number of LLDN Base Timeslots in LLDN Superframe | LLDN Group Acknow- ledgment | FCS |
| MHR | MAC Payload | MFR |

Figure .—Format of the LLDN Beacon frame

The order of the fields of the LLDN Beacon frame shall conform to the order of the general LLDN frame as illustrated in .

The LLDN Beacon frame has a short MHR containing the LLDN Frame Control field of one octet.

In the LLDN Frame Control field, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN Beacon frame, as shown in .

The LLDN Beacon Flags field contains control information. The structure of the LLDN Beacon Flags field is shown in .

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits: 0–2** | **3** | **4** | **5–7** |
| LLDN Transmission State | LLDN Transmission Direction | Reserved | Number of LLDN Base Timeslots per LLDN Management Timeslot |

Figure .—Structure of LLDN Beacon Flags field of LLDN Beacon frame

The LLDN Transmission State field defines the LLDN transmission state. The values for the different LLDN transmission states are specified in .

Table G.3—Transmission State settings

|  |  |
| --- | --- |
| **Bits 0–2** | **Transmission State** |
| 000 | LLDN Online state (described in G.3.1.4) |
| 100 | LLDN Discovery state (described in G.3.1.2) |
| 110 | LLDN Configuration state (described in G.3.1.3) |
| 111 | LLDN State Reset: The LLDN devices reset their state of the LLDN discovery or LLDN configuration |

The LLDN Transmission Direction field indicates the transmission direction of all bidirectional LLDN timeslots during this LLDN superframe. If the LLDN Transmission Direction field is set to zero, the direction of all bidirectional LLDN timeslots is uplink (from LLDN device to LLDN PAN coordinator). If the LLDN Transmission Direction field is set to one, the direction of all bidirectional LLDN timeslots is downlink (from LLDN PAN coordinator to LLDN device). The LLDN Transmission Direction field is only used in LLDN Online state.

The Number of LLDN Base Timeslots per LLDN Management Timeslot field contains the number of LLDN base timeslots per LLDN management timeslot. This value applies to both the downlink and the uplink LLDN management timeslot. A value of zero indicates that there are no LLDN management timeslots available in the LLDN superframe. A non-zero value indicates that there are one downlink and one uplink LLDN management timeslot available in the LLDN superframe. Each of the LLDN management timeslots is of duration of the given number of LLDN Base Timeslots.

The LLDN PAN coordinator ID field contains the 8-bit simple address (i.e., *macSimpleAddress*) of the LLDN PAN coordinator.

The LLDN Configuration Sequence Number field contains an integer number that identifies, together with the LLDN PAN coordinator ID, the current configuration of the LLDN. The LLDN configuration sequence number is initialized to a random number at the LLDN PAN coordinator.

The Max LLDN Data Size field contains the expected maximum number of octets of the LLDN data payload of an LLDN Data frame.

The content of the Max LLDN Data Size field is used in the calculation of the actual size of the LLDN base timeslot in seconds. The actual size of the LLDN base timeslot is calculated as

*tTS* : = (*p* *sp* + (*m* + *n*) *sm* + *macSifsPeriod* symbols / *v*

if *m* + *n* *aMaxSIFSFrameSize* octets or

*tTS* : = (*p* *sp* + (*m* + *n*) *sm* + *macLifsPeriod* symbols / *v*

if *m* + *n* > *aMaxSIFSFrameSize* octets.

The description of the parameters is given in . Furthermore, contains an example with values for the 2450 MHz O-QPSK PHY.

Table G.4—Description and Example of parameters for calculation of actual LLDN base timeslot size

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **Value for 2450 MHz O-QPSK PHYwith no security enabled** |
| *p* | Number of octets of PHY header | 6 octets |
| *sp* | Number of symbols per octet in PHY header | 2 symbols per octet |
| *m* | Number of octets of MAC overhead (MHR + MFR) | 3 octets for LLDN Data frames |
| *n* | Expected maximum number of octets of LLDN data payload | Value of Max LLDN Data Size field of LLDN Beacon frame |
| *sm* | Number of symbols per octet in PSDU | 2 symbols per octet |
| *v* | Symbol rate | 62 500 symbols/s |
| *macSifsPeriod* | The minimum time forming a SIFS period. | 12 symbols |
| *macLifsPeriod* | The minimum time forming a LIFS period. | 40 symbols |
| *aMaxSIFSFrameSize* | The maximum size of an MPDU, that can be followed by a SIFS period. | 18 octets |
| *tTS* | Actual size of LLDN base timeslot in seconds | with n=2 octets: 0.544 mswith n=20 octets: 1.568 ms |

The Number of Base Timeslots in Superframe field contains an integer number that represents the number of base timeslots for LLDN devices immediately following the management timeslots of the superframe (corresponds to *macLldnNumTs*). The Number of Base Timeslots in the Superframe field is only present in the Online state.

The LLDN Group Acknowledgment field is a bitmap of length (*macLldnNumTs* *macLldnNumRetransmitTs*) bits, padded to a multiple of 8 bits, as shown in , to indicate successful transmissions by LLDN devices from the previous LLDN superframe. The size of the bitmap shall always be a multiple of 8 after padding with additional zeros at the end if necessary. In the separate LLDN group acknowledgment configuration, this field is not present in the LLDN Beacon. The LLDN Group Acknowledgment field is only present in LLDN Online mode. The LLDN Group Acknowledgment field contains a bit field where each bit corresponds to a LLDN base timeslot associated with an LLDN device excluding LLDN retransmission timeslots. Bit b0 of the LLDN Group Acknowledgement bitmap corresponds to the first LLDN base timeslot after the *macLldnNumRetransmitTs* LLDN retransmission timeslots, bit b1 of the LLDN Group Acknowledgment bitmap corresponds to the second LLDN base timeslot, and so on. A bit value of one means the corresponding uplink transmission in the previous LLDN superframe was successful, and a bit value of zero means the corresponding uplink transmission in the previous LLDN superframe failed or there was no uplink transmission. In the case of a bit value of zero, the LLDN device is allocated an LLDN timeslot for retransmission in the current LLDN superframe. Because concatenated LLDN timeslots are multiples of LLDN base timeslots, a concatenated LLDN timeslot of length of *n* LLDN base timeslots shall have *n* bits in the LLDN Group Acknowledgment bitmap at the corresponding positions. If the data frame has been received during an LLDN shared group timeslot, all corresponding bits of this LLDN shared group timeslot shall be set accordingly in the LLDN Group Acknowledgment bitmap.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits: 0** | **1** | **...** | **(*macLldnNumTs* –*****macLldnNumRetransmitTs*****– 1)** | **... n\* 8–1** |
| Acknowledgment of trans­mission in LLDN base timeslot *macLldnNumRetransmitTs* + 1 | Acknowledgment of trans­mission in LLDN base timeslot *macLldnNumRetransmitTs* + 2 | ... | Acknowledgment of trans­mission in LLDN base timeslot *macLldnNumTs* | Padding |

Figure .—Structure of LLDN Group Acknowledgment bitmap

### **LLDN Data frame format**

The LLDN Data frame is sent during LLDN Online mode in LLDN device timeslots. The LLDN Data frame shall be formatted as illustrated in .

|  |  |  |
| --- | --- | --- |
| **Octets: 1** | **variable** | **2** |
| LLDNFrame Control | Data Payload | FCS |
| MHR | MAC Payload | MFR |

Figure .—Format of LLDN Data frame

The order of the fields of the LLDN Data frame shall conform to the order of the general MAC frame as illustrated in Figure 86.

The LLDN Data frame has a short MHR containing the LLDN Frame Control field of one octet.

In the LLDN Frame Control field, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN Data frame, as shown in .

The payload of an LLDN Data frame shall contain the sequence of octets that the next higher layer has requested the MAC sublayer to transmit.

### **LLDN Acknowledgment frame format**

The LLDN Acknowledgment frame is sent during LLDN Online mode in bidirectional LLDN timeslots. The LLDN Acknowledgment frame shall be formatted as illustrated in .

|  |  |  |  |
| --- | --- | --- | --- |
| **Octets: 1** | **1** | **variable** | **2** |
| LLDN Frame Control | LLDN Acknowledg­ment Type | Acknowledgment Payload | FCS |
| MHR | MAC payload | MFR |

Figure .—Format of the LLDN Acknowledgment frame

The order of the fields of the LLDN Acknowledgment frame shall conform to the order of the general LLDN frame as illustrated in .

The LLDN Acknowledgment frame has a short MHR containing the LLDN Frame Control field of one octet.

In the LLDN Frame Control field, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN Acknowledgment frame, as shown in .

The LLDN Acknowledgment Type field indicates the type of frame that is acknowledged or the type of LLDN acknowledgment. Possible values are listed in .

Table G.5—LLDN Acknowledgment types

|  |  |
| --- | --- |
| **Acknowledged frame typeLLDN Acknowledgment type** | **Acknowledgment payload** |
| LLDN Configuration Request frame | No |
| LLDN Data frame | No |
| LLDN Data Group ACK type | Yes |
| LLDN Discover Response frame | No |

The Acknowledgment Payload field is only available in certain LLDN acknowledgment types as depicted in . The structure and the length of the Acknowledgment Payload field depends on the value of the LLDN Acknowledgment Type field.

The structure of the Acknowledgment Payload field of the LLDN Data Group ACK frame is shown in .



Figure .—Format of the LLDN Data Group ACK frame

The LLDN Source ID field shall be an 8-bit simple address that identifies the transmitting LLDN PAN coordinator.

The LLDN Group Ack Flags field is a bitmap of size equal to the smallest multiple of 8 that is greater than or equal to the number of uplink LLDN base timeslots. It indicates the states of transmissions of the LLDN devices in the uplink timeslots of the current LLDN superframe. A bit set to one indicates the fact that the LLDN PAN coordinator received the data frame successfully in the corresponding LLDN timeslot. A value of zero means, that the LLDN PAN coordinator failed in receiving a data frame in the corresponding LLDN timeslot from of the LLDN device.

### **LLDN MAC Command frame format**

There are different types of LLDN MAC Command frames sharing a common, general structure, differing only in the Command Payload. The LLDN MAC Command frame shall be formatted as illustrated in .

|  |  |  |  |
| --- | --- | --- | --- |
| **Octets: 1** | **1** | **variable** | **2** |
| LLDN Frame Control | CommandFrame Identifier | Command Payload | FCS |
| MHR | MAC payload | MFR |

Figure .—Format of the LLDN MAC Command frame

The order of the fields of the LLDN MAC Command frame shall conform to the order of the general LLDN frame as illustrated in .

The LLDN MAC Command frame has a short MHR containing the LLDN Frame Control field of one octet.

In the LLDN Frame Control field, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

The Command Frame Identifier field identifies the MAC command being used. This field shall be set to one of the non-reserved values listed in Table 50.

The Command Payload field contains the MAC command itself. The formats of the individual LLDN commands are described in . The Command Payload field is of variable length and contains data specific to the different MAC Command frame types.

## LLDN commands

### **LLDN Discover Response command**

#### **General**

The LLDN Discover Response command contains the configuration parameters that have to be transmitted to the LLDN PAN coordinator as input for the configuration process in an LLDN.

This command shall only be sent by an LLDN device that has received an LLDN Beacon (refer to ) indicating LLDN Discovery mode as determined through the procedures of the LLDN Discovery state as described in G.3.1.2.

All LLDN devices shall be capable of transmitting this command, although an RFD is not required to be capable of receiving it.

The command payload of the LLDN Discover Response frame shall be formatted as illustrated in .

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Octets: 1** | **8** | **1** | **variable** | **variable** |
| Command Frame Identifier (defined in Table 50) | LLDN Device Extended MAC Address | LLDN Discover Response Flags | LLDN Discovery Parameters | LLDN Discover Response Payload |

Figure .—LLDN Discover Response command MAC payload

#### **MHR fields**

The LLDN Discover Response command can be sent using both MAC Command frames described in 7.3.4 or LLDN MAC Command frames described in .

If sent in a MAC Command frame, the Frame Type field of the Frame Control field shall contain the value that indicates a MAC command frame, as shown in Table 5. The Source Addressing Mode field of the Frame Control field shall be set to three (64-bit extended addressing). The Source Address field shall contain the value of *aExtendedAddress*.

If sent in an LLDN MAC Command frame, the Frame Type field of the LLDN Frame Control field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN Discover Response command frame as defined in Table 50.

#### **LLDN Device Extended MAC Address field**

The LLDN Device Extended MAC Address field contains the Extended MAC address of the LLDN device to be included in the LLDN (originator of the LLDN Discover Response frame).

#### **LLDN Discover Response Flags field**

The LLDN Discover Response Flags field is reserved for future use.

#### **LLDN Discovery Parameters field**

The LLDN Discovery Parameters field contains the configuration parameters that are required by the LLDN device and that have to be transmitted to the LLDN PAN coordinator as input for the LLDN configuration process. The format of the LLDN Discovery Parameters field is illustrated in .

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Octets: 2** | **0-8** | **0-8** | **0-8** | **0-8** |
| Number of LLDN Timeslots | List of Dedicated Uplink LLDN Timeslot Lengths | List of Shared Group Uplink LLDN Timeslot Lengths | List of Dedicated Bidirectional LLDN Timeslot Lengths | List of Shared Group Bidirectional LLDN TimeslotLengths |

Figure .: Format of the LLDN Discovery Parameters field

##### **Number of LLDN Timeslots subfield**

The Number of LLDN Timeslots field contains the number of LLDN timeslots required by the LLDN device, for each type of LLDN timeslot, and is composed of four subfields, as illustrated in . Each non-reserved subfield ranges from 0 to 8.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits: 0-2** | **3-6** | **7-9** | **10-12** | **13-16** |
| Number of Dedicated Uplink LLDN Timeslots | Number of Shared Group Uplink LLDN Timeslots | Number of Dedicated Bidirectional LLDN Timeslots | Number of Shared Group Bidirectional LLDN Timeslots | Reserved |

Figure .—Format of the Number of LLDN Timeslots subfield

##### **List of LLDN Timeslot Length fields**

The List of Dedicated Uplink LLDN Timeslot Lengths field, the List of Shared Group Uplink LLDN Timeslot Lengths field, the List of Dedicated Bidirectional LLDN Timeslot Lengths field, and the List of Shared Group Bidirectional LLDN Timeslot Lengths field contain a list of LLDN Timeslot Lengths subfields, the corresponding number of LLDN Timeslot Lengths fields is defined in the Number of Dedicated Uplink LLDN Timeslots field, the Number of Shared Group Uplink LLDN Timeslots field, the Number of Dedicated Bidirectional LLDN Timeslots field, and the Number of Shared Group Bidirectional LLDN Timeslots field of the Number of Required LLDN Timeslots field, respectively.

The LLDN device is the LLDN slot owner in dedicated LLDN timeslots. The LLDN device is not the LLDN slot owner in shared group LLDN timeslots.

The LLDN Timeslot Lengths subfield specifies the maximum size of the LLDN Data frame payload, in octets, that shall be contained in the required LLDN timeslot. The format of the LLDN Timeslot Lengths field is shown in .

|  |  |
| --- | --- |
| **Bits: 0-6** | **7** |
| Maximum LLDN Data Frame Payload Size | Reserved |

Figure .—Format of LLDN Timeslot Lengths subfield

#### **LLDN Discover Response Payload field**

The LLDN Discover Response Payload field contains application-specific and vendor-specific information of the LLDN device for the LLDN discover response that is not part of this standard.

### **LLDN Configuration Status command**

#### **General**

The LLDN Configuration Status command contains the configuration parameters that are currently configured at the LLDN device as input for the configuration process in an LLDN.

This command shall only be sent by an LLDN device that has received an LLDN Beacon (described in ) indicating LLDN Configuration mode as determined through the procedures of the Configuration mode described in G.3.1.3.

All LLDN devices shall be capable of transmitting this command, although an RFD is not required to be capable of receiving it.

The command payload of the LLDN Configuration Status frame shall be formatted as illustrated in .

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Octets: 1** | **8** | **2** | **1** | **1** | **variable** | **variable** |
| Command Frame (defined in Table 50) | LLDN Device Extended MAC Address | LLDN Device Short MAC Address | LLDN Device Simple MAC Address | LLDN Configuration Status Flags | LLDN Configuration Parameters | LLDN Configuration Status Payload |

Figure .—Configuration Status command MAC payload

#### **MHR fields**

The LLDN Configuration Status command can be sent using both MAC Command frames described in 7.3.4 or LLDN MAC Command frames described in .

If sent in a MAC Command frame, the Frame Type field of the Frame Control field shall contain the value that indicates a MAC Command frame, as shown in Table 5. The Source Addressing Mode field of the Frame Control field shall be set to one (8-bit short addressing) or three (64-bit extended addressing). The Source Address field shall contain the value of *macSimpleAddress* if the Source Addressing Mode field is set to one or *aExtendedAddress* if the Source Addressing Mode field is set to three.

If sent in an LLDN MAC Command frame, the Frame Type field of the LLDN Frame Control field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN Configuration Status command frame as defined in Table 50.

#### **LLDN Device MAC Address fields**

The LLDN Device Extended MAC Address field contains the Extended MAC address of the LLDN device to be configured in the LLDN (originator of LLDN Configuration Status frame). The LLDN Device Short MAC Address field and the LLDN Device Simple MAC Address field contain the short MAC address and simple MAC address, respectively, assigned to the LLDN device (originator of LLDN Configuration Status frame) in the previous LLDN configuration.

A value of 0x0000 and 0x00 indicates that no short MAC address or simple MAC address of the LLDN device has been configured.

#### **LLDN Configuration Status Flags field**

The LLDN Configuration Status Flags field is reserved for future use.

#### **LLDN Configuration Parameters field**

The LLDN Configuration Parameters field contains the configuration parameters that are currently configured at the LLDN device. The format of the LLDN Configuration Parameters field is illustrated in .

|  |  |
| --- | --- |
| **Octets: 1** | **variable** |
| LLDN Configuration Sequence Number | Required LLDN Timeslot Info |

Figure .—Format of the LLDN Configuration Parameters field

The LLDN Configuration Sequence Number field contains the last LLDN configuration sequence number known by the LLDN device.

The Required LLDN Timeslot Info field contains the list of LLDN timeslots required by the LLDN device, as described in G.5.1.6.

#### **LLDN Configuration Status Payload field**

The LLDN Configuration Status Payload field contains application-specific and vendor-specific information of the LLDN device for the LLDN configuration status that is not part of this standard.

### **LLDN Configuration Request command**

#### **General**

The LLDN Configuration Request command contains the configuration parameters that the receiving LLDN device shall use during the Online state. This command shall only be sent by an LLDN PAN coordinator in response to a received LLDN Configuration Status frame of an LLDN device during the Configuration state. Only LLDN PAN coordinators are requested to be capable of transmitting this command; LLDN RFDs are required to be capable of receiving it.

The command payload of the LLDN Configuration Request frame shall be formatted as illustrated in .

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Octet: 1** | **8** | **2** | **1** | **1** | **variable** | **variable** |
| Command Frame Identifier (defined in Table 50) | LLDN Device Extended MAC Address | LLDN Device Short MAC Address | LLDN Device Simple MAC Address | LLDN Configuration Request Flags | LLDN Configuration Parameters | LLDN Configuration Request Payload |

Figure .—Configuration Request command MAC payload

#### **MHR fields**

The LLDN Configuration Request command can be sent using both MAC Command frames described in 7.3.4 or LLDN MAC Command frames described in .

If sent in a MAC Command frame, the Frame Type field of the Frame Control field shall contain the value that indicates a MAC Command frame, as shown in Table 5. The Source Addressing Mode field of the Frame Control field shall be set to one (8-bit short addressing) or three (64-bit extended addressing). The Destination Address field shall contain the value of the source address of the corresponding LLDN Configuration Status frame.

If sent in an LLDN MAC Command frame, the Frame Type field of the LLDN Frame Control field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN Configuration Request command frame as defined in Table 50.

#### **LLDN Device MAC Address fields**

The LLDN Device Extended MAC Address field contains the Extended MAC address of the LLDN device to be configured in the LLDN (destination of LLDN Configuration Request frame). The LLDN Device Short MAC Address field and the LLDN Device Simple MAC Address field contain the assigned short MAC address and simple MAC address, respectively, assigned to the LLDN device (destination of LLDN Configuration Request frame) in this LLDN configuration.

#### **LLDN Configuration Request Flags field**

The LLDN Configuration Request Flags field is reserved for future use.

#### **LLDN Configuration Parameters field**

The LLDN Configuration Parameters field contains the new configuration parameters that are sent to the LLDN device in order to either configure it or reconfigure it. The format of the LLDN Configuration Parameters field is illustrated in .

|  |  |  |
| --- | --- | --- |
| **Octets: 1** | **4** | **variable** |
| LLDN Configuration Sequence Number | LLDN Superframe Configuration | Configured LLDN Timeslot Info |

Figure .—Format of LLDN Configuration Paramters field

##### **LLDN Configuration Sequence Number subfield**

The LLDN Configuration Sequence Number subfield contains the LLDN configuration sequence number for this new LLDN configuration.

##### **LLDN Superframe Configuration subfield**

The LLDN Superframe Configuration subfield contains the LLDN superframe configuration, as illustrated in Figure G.30.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits: 0-17** | **18** | **19** | **20-23** | **24-31** |
| Reserved | LLDN Management Timeslots Present | Separate LLDN GACK Present | Channel Page | Channel Number |

Figure .—Format of Superframe Configuration subfield.

The LLDN Management Timeslots Present bit indicates whether Management Timeslots are present in the LLDN Online State of this LLDN configuration. It shall be set to 0 if no LLDN Management Timeslots are present, set to 1 otherwise.

The Separate LLDN GACK Present bit indicates whether a separate LLDN Group Acknowledgement timeslot is present in the LLDN Online State of this LLDN configuration. It shall be set to 0 if no LLDN Group Acknowledgement timeslot is present, set to 1 otherwise.

The Channel Page field indicates the channel page to be used in the LLDN Online State of this LLDN configuration.

The Channel Number field indicates the channel number to be used in the LLDN Online State of this LLDN configuration. Together with the Channel Page field it defines the transmission channel to be used.

##### **Configured LLDN Timeslot Info subfield**

The Configured LLDN Timeslot Info subfield contains the list of LLDN timeslots corresponding to the LLDN configuration sequence number of this new LLDN configuration as illustrated in .

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Octets: 2** | **variable** | **variable** | **variable** | **variable** |
| Number of LLDN Timeslots | List of Dedicated Uplink LLDN Timeslot Descriptors | List of Shared Group Uplink LLDN Timeslot Descriptors | List of Dedicated Bidirectional LLDN Timeslot Descriptors | List of Shared Group Bidirectional LLDN Timeslot Descriptors |

Figure .—Format of Configured LLDN Timeslot Info subfield

The Number of LLDN Timeslots subfield contains the number of LLDN timeslots configured to the LLDN device (destination of LLDN Configuration Request frame) by the LLDN PAN coordinator (source of LLDN Configuration Request frame). The format of the Number of LLDN Timeslots subfield is illustrated in in .

The List of Dedicated Uplink LLDN Timeslot Descriptors field, the List of Shared Group Uplink LLDN Timeslot Descriptors field, the List of Dedicated Bidirectional LLDN Timeslot Descriptors field, and the List of Shared Group Bidirectional LLDN Timeslot Descriptors field contain a list of LLDN Timeslot Descriptors to LLDN timeslots assigned to the LLDN device (destination of LLDN Configuration Request frame) by the LLDN PAN coordinator. The corresponding number of LLDN Timeslot Descriptor fields is defined in the respective subfields of the Number of LLDN Timeslots subfield. The format of the LLDN timeslot descriptor is given in .

The LLDN device is the LLDN slot owner in dedicated LLDN timeslots. The LLDN device is not the LLDN slot owner in shared group LLDN timeslots.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Octets: 1** | **1** | **1** | **1** | **1** |
| Index of LLDN Timeslot | Offset of tSlotStart | Offset of tSlotTxOwner | Offset of tSlotTxGW | Offset of tSlotEnd |

Figure .—Format of LLDN Timeslot Descriptor

The Index of LLDN Timeslot field contains the absolute number of the LLDN timeslot, that is its index in the list of the LLDN superframe timeslots, excluding LLDN beacon timeslot and LLDN management timeslots. It is used to find the corresponding bit in the LLDN Group Acknowledgement field of the LLDN beacon.

The Offset of tSlotStart field, Offset of tSlotTxOwner field, Offset of tSlotTxGW field, Offset of tSlotEnd field contain the number of LLDN base timeslots.

#### **LLDN Configuration Request Payload field**

The LLDN Configuration Request Payload field contains application-specific and vendor-specific information of the LLDN PAN coordinator for the LLDN configuration request that is not part of this standard.

### **LLDN Clear To Send (CTS) Shared Group command**

#### **General**

The LLDN Clear To Send (CTS) Shared Group command indicates to the LLDN devices of the star network that they now may use the timeslot for transmitting their own data with a simplified CSMA-CA.

This command shall only be sent by an LLDN PAN coordinator in an LLDN timeslot after *tSlotTxOwner* has been elapsed and the LLDN timeslot owner is not transmitting. For further information on channel access within LLDN timeslots refer to G.2.2.

Only LLDN PAN coordinators shall be capable of transmitting this command, all other LLDN devices shall be capable of receiving it.

The command payload of the LLDN CTS Shared Group frame shall be formatted as illustrated in .

|  |  |
| --- | --- |
| **Octet: 1** | **1** |
| Command Frame Identifier (defined in Table 50) | LLD Network ID |

Figure .—Clear To Send (CTS) Shared Group command MAC payload

#### **MHR fields**

The LLDN CTS Shared Group command shall be sent using LLDN MAC Command frames.

In the LLDN Frame Control field of the LLDN MAC Command frame, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN CTS Shared Group command frame as defined in Table 50.

#### **LLD Network ID field**

The LLD Network ID field contains an identifier specific to the LLDN PAN coordinator.

### **LLDN Request To Send (RTS) command**

#### **General**

The LLDN Request To Send (RTS) command may be used by an LLDN device to indicate to the LLDN PAN coordinator and to the other devices of the LLD star network that it wants to transmit data with a simplified CSMA-CA. The LLDN RTS frame is transmitted using a simplified CSMA-CA.

This command shall only be sent by an LLDN device in an LLDN timeslot after tSlotTxOwner has been elapsed and an LLDN CTS Shared Group frame has been received from the LLDN PAN coordinator.

LLDN devices shall be capable of transmitting and receiving this command.

The command payload of the LLDN RTS frame shall be formatted as illustrated in .

|  |  |  |
| --- | --- | --- |
| **Octet: 1** | **1** | **1** |
| Command Frame Identifier (defined in Table 50) | Short Originator Address | LLD Network ID |

Figure .—LLDN Request To Send (RTC) command MAC payload

#### **MHR fields**

The LLDN RTS command shall be sent using LLDN MAC Command frames.

In the LLDN Frame Control field of the LLDN MAC Command frame, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN RTS frame as defined in Table 50.

#### **Short Originator Address field**

The Short Originator Address field contains the 1-octet simple address of the LLDN device sending this LLDN RTS frame.

#### **LLD Network ID field**

The LLD Network ID field contains an identifier specific to the LLDN PAN coordinator. It has to be identical to the LLD Network ID of the corresponding received LLDN CTS Shared Group frame.

### **LLDN Clear To Send (CTS) command**

#### **General**

The LLDN Clear To Send (CTS) command indicates to a specific LLDN device of the LLD star network that it may now use the LLDN timeslot for transmitting its own data with a simplified CSMA-CA. The LLDN CTS command is broadcast by the LLDN PAN coordinator in response to a received LLDN RTS command.

LLDN PAN coordinators shall be capable of transmitting this command, other LLDN devices shall be capable of receiving it.

The command payload of the LLDN CTS frame shall be formatted as illustrated in .

|  |  |  |
| --- | --- | --- |
| **Octet: 1** | **1** | **1** |
| Command Frame Identifier (defined in Table 50) | Short Destination Address | LLD Network ID |

Figure .—LLDN Clear To Send (CTS) command MAC payload

#### **MHR fields**

The LLDN CTS command shall be sent using LLDN MAC Command frames.

In the LLDN Frame Control field of the LLDN MAC Command frame, the Frame Type field shall contain the value that indicates an LLDN frame, as shown in Table 5, and the LLDN Frame Subtype field shall contain the value that indicates an LLDN MAC Command frame, as shown in .

#### **Command Frame Identifier field**

The Command Frame Identifier field contains the value for the LLDN CTS frame as defined in Table 50.

#### **Short Destination Address field**

The Short Destination Address field contains the 1-octet simple address of the LLDN device to which this LLDN CTS frame is directed.

#### **LLD Network ID field**

The LLD Network ID field contains an identifier specific to the LLDN PAN coordinator that shall be identical to the LLD Network ID of the corresponding received LLDN RTS frame.

## LLDN primitives

### **General**

When the optional LLDN mode is implemented (i.e., *macLldnCapable* = TRUE), the services shown in shall be implemented. These LLDN primitives control the different LLDN modes for the LLDN configuration and LLDN operation of the LLDN superframe in an LLDN.

Table G.6—LLDN primitives

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Request** | **Indication** | **Response** | **Confirm** |
| MLME-LLDN-DISCOVERY |   | — | — |   |
| MLME-LLDN-CONFIGURATION |   | — | — |   |
| MLME- LLDN-ONLINE |   |   | — | — |

### **MLME-LLDN-DISCOVERY.request**

This primitive switches the LLDN into the LLDN Discovery state.

The semantics of this primitive are:

 MLME-LLDN-DISCOVERY.request (

 LowLatencyNetworkConfiguration

 )

The primitive parameters are defined in .

Table G.7—MLME-LLDN-DISCOVERY.request parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| LowLatencyNet- workConfiguration | Set of octets of variable length | ⎯ | Contains the necessary LLDN configuration parameters from the next higher layer for the LLDN in LLDN Discovery state |

The MLME-LLDN-DISCOVERY.request primitive is generated by the next higher layer of an LLDN PAN coordinator and issued to its MLME to switch the LLDN into the LLDN Discovery state as described in G.3.1.2.

When the MLME of an LLDN PAN coordinator receives the MLME-LLDN-DISCOVERY.request primitive, it sets the Transmission State field in the LLDN Beacon Flags field of the payload of the LLDN Beacons to the value for LLDN Discovery state as defined in and follows the procedures as defined for LLDN Discovery state in G.3.1.2.

### **MLME-LLDN-DISCOVERY.confirm**

This primitive indicates the end of the LLDN Discover state and gives the status of the LLDN Discovery state to a higher layer.

The semantics of this primitive are:

 MLME-LLDN-DISCOVERY.confirm (

 status,

 DiscoveredDevices,

 LowLatencyNetworkConfiguration

 )

The primitive parameters are defined in .

Table G.8—MLME-LLDN-DISCOVERY.confirm parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| status | Enumeration | SUCCESS, NO\_LLDN\_DEVICE, ABORTED | The status of the LLDN Discovery state when finished. |
| DiscoveredLLDN-Devices | Integer | 0 .. 128 | Number of discovered LLDN devices. |
| LowLatencyNetwork- Configuration | Set of octets of variable length | — | Discovered information of the discovered LLDN devices of the LLDN for the next higher layer |
| DiscoveryModeStatus | ? | ? | ? |

The MLME-LLDN-DISCOVERY.confirm primitive is generated by the MLME of the LLDN PAN coordinator and issued to its next higher layer to indicate the end of the LLDN Discovery state in the LLDN. It returns the number of discovered LLDN devices and the collected information about the discovered LLDN devices in the LLDN to the next higher layer. The MLME-LLDN-DISCOVERY.confirm primitive will either return a status SUCCESS, indicating that all LLDN devices with *macLLenabled* set to TRUE within range have been discovered, or an error code of NO\_LLDN\_DEVICE (expected to discover LLDN device, but none found) or ABORTED (LLDN Discovery state finished before all devices had been discovered).

When the next higher layer of an LLDN PAN coordinator receives the MLME-LLDN-DISCOVERY.confirm primitive, the LLDN PAN coordinator determines a configuration of the LLDN based on the status and the information about the discovered LLDN devices received in DiscoveredLLDNDevices and LowLatencyNetworkConfiguration DiscoveryModeStatus. It uses an algorithm outside the scope of this standard. The next higher layer of the LLDN coordinator should then issue the MLME-LLDN-CONFIGURATION.request primitive to its MLME.

### **MLME-LLDN-CONFIGURATION.request**

This primitive switches the LLDN into the LLDN Configuration state.

The semantics of this primitive are:

 MLME-LLDN-CONFIGURATION.request (

 LowLatencyNetworkConfiguration

 )

The primitive parameters are defined in .

Table G.9—MLME-LLDN-CONFIGURATION.request parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| LowLatencyNet- workConfiguration | Set of octets of variable length | — | Contains the necessary configuration parameters for the LLDN in the LLDN Configuration state |

The MLME-LLDN-CONFIGURATION.request primitive is generated by the next higher layer of an LLDN PAN coordinator and issued to its MLME to switch the LLDN into the LLDN Configuration state as described in G.3.1.3.

When the MLME of an LLDN PAN coordinator receives the MLME-LLDN-CONFIGURATION.request primitive, it sets the Transmission State field in the LLDN Beacon Flags field of the payload of the LLDN Beacons to the value for the LLDN Configuration state as indicated in and follows the procedures as defined for LLDN Configuration state in G.3.1.3.

### **MLME-LLDN-CONFIGURATION.confirm**

This primitive indicates the end of the LLDN Configuration state and gives the status of the LLDN Configuration state to the next higher layer.

The semantics of this primitive are:

 MLME-LLDN-CONFIGURATION.confirm (

 status,

 ConfiguredDevices,

 LowLatencyNetworkConfiguration

 )

The primitive parameters are defined in .

Table G.10—MLME-LLDN-CONFIGURATION.confirm parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| status | Enumeration | SUCCESS, NO\_LLDN\_DEVICE, ABORTED | The status of the LLDN Configuration state when finished. |
| ConfiguredLLDN-Devices | Integer | 0 .. 128 | Number of configured LLDN devices. |
| LowLatencyNetwork- Configuration | Set of octets of variable length | ⎯ | Configuration of the configured LLDN devices of the LLDN for the next higher layer. |

The MLME-LLDN-CONFIGURATION.confirm primitive is generated by the MLME of the LLDN PAN coordinator and issued to its next higher layer to indicate the end of the LLDN Configuration state in the LLDN. It returns the number of configured LLDN devices and the collected LLDN configuration information about the configured LLDN devices in the LLDN to the next higher layer. The MLME-LLDN-CONFIGURATION.confirm primitive will either return a status SUCCESS, indicating that all LLDN devices with *macLLenabled* set to TRUE within range have been configured, or an error code of NO\_LLDN\_DEVICE (expected to configure device, but none found) or ABORTED (LLDN Configuration state finished before all discovered LLDN devices had been configured).

When the next higher layer of an LLDN PAN coordinator receives the MLME-LLDN- CONFIRMATION.confirm primitive, the next higher layer of the LLDN PAN coordinator should issue the MLME-LLDN-ONLINE.request (status is SUCCESS), the MLME-LLDN-CONFIGURATION.request (status is ABORTED), or the MLME-LLDN-DISCOVERY.request (status is NO\_LLDN\_DEVICE) primitive to its MLME.

### **MLME-LLDN-ONLINE.request**

This primitive switches the LLDN into the LLDN Online state.

The semantics of this primitive are:

 MLME-LLDN-ONLINE.request (

 )

The MLME-LLDN-ONLINE.request primitive is generated by the next higher layer of an LLDN PAN coordinator and issued to its MLME to switch the LLDN into the LLDN Online state (G.3.1.4).

When the MLME of an LLDN PAN coordinator receives the MLME-LLDN-ONLINE.request primitive, the LLDN PAN coordinator shall switch over to LLDN Online state by setting appropriate flags in its LLDN Beacon payload, as described in , and follows the procedures as defined for LLDN Online state in G.3.1.4.

### **MLME-LLDN-ONLINE.indication**

This primitive indicates any problems during the LLDN Online state to the next higher layer.

The semantics of this primitive are:

 MLME-LLDN-ONLINE.indication (

 status,

 AdditionalInformation

 )

The primitive parameters are defined in .

Table G.11—MLME-LLDN-ONLINE.indication parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| status | Enumeration | NONE, UNSPECIFIED | Contains the status in the LLDN including any discovered problems. |
| AdditionalInformation | Set of octets of variable length | ⎯ | Additional supporting information |

The MLME-LLDN-ONLINE.indication primitive is generated by the MLME of any LLDN device and issued to its next higher layer to indicate the status and any problems that occurred in the LLDN during the operation in LLDN online mode. It returns the indication of the problem (NONE or UNSPECIFIED) and the additional supporting information to the higher layer.

When the next higher layer of an LLDN device receives the MLME-LLDN-ONLINE.indication primitive, the LLDN device determines appropriate countermeasures using an algorithm outside the scope of this standard.

### **Association primitives**

When the association primitives of 8.2.3 are used in an LLDN (*macLldnEnabled* = TRUE), the MLME-ASSOCIATE.request primitive, the MLME-ASSOCIATE.indication primitive, the MLME-ASSOCIATE.response primitive, and the MLME-ASSOCIATE.confirm primitive contain the following additional primitive parameter as defined in :

Table G.12—LLDN specific parameter for association primitives

|  |  |  |  |
| --- | --- | --- | --- |
| LLDNetworkInfo | Set of octets of variable length | — | Information for association specific to LLD networks from the next higher layer. Only available if *macLldnEnabled* is TRUE. |

## LLDN extensions to MAC data service

In Low Latency Deterministic Networks (LLDNs), the primitives MCPS-DATA.request, MCPS-DATA.confirm, and MCPS-DATA.indication accept for parameters SrcAddrMode and DstAddrMode also the value SIMPLE\_ADDRESS in their valid range.

## LLDN specific MAC PIB attributes

In Low Latency Deterministic Networks (LLDNs), 8.4.2 applies. Additional MAC PIB attributes are required for LLDNs. These are stated in . Some MAC PIB attributes have a different default value in LLDNs as stated in .

Table G.13—LLDN specific MAC PIB attributes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** | **Default** |
| *macLldnNum- Ts* | Integer | 0 … 254 | Number of LLDN base timeslots within LLDN superframe excluding LLDN timeslot for LLDN Beacon frame and LLDN management timeslots | 20 |
| *macLldnNum- UplinkTs* | Integer | 0 … *macLldnNumTs* | Number of uplink LLDN base timeslots within LLDN superframe for unidirectional communication (uplink) as defined in G.1. | 20 |
| *macLldnNum- RetransmitTs* | Integer | 0 … *macLldnNum-UplinkTs/2* | Number of uplink LLDN base timeslots reserved for retransmission | 0 |
| *macLldnNum- BidirectionalTs* | Integer | 0 … *macLldnNumTs* | Number of bidirectional LLDN base timeslots as defined in G.1 within LLDN superframe for bidirectional communication | 0 |
| *macLldnMgmt­Ts* | Boolean | TRUE or FALSE | Indicates presence of LLDN management timeslots in LLDN Online state | FALSE |
| *macLldnLow- LatencyNWid* | Integer | 0x00–0xff | The 8-bit identifier of the LLDN on which the LLDN device is operating. If this value is 0xff, the LLDN device is not associated. | 0xff |
| *macLldnTime­slotInfo* | Imple- men- tation specific |  | Information related to a LLDN base timeslot, for instance, MAC addresses mapped to the LLDN base timeslot. For the LLDN PAN coordinator, there are *macLldnNumTs* attributes of *macLldnTimeslotInfo*. | Set during LLDN Configu- ration state |
| *macLldn­DiscoveryModeTimeout* | Integer | 0…256 | The LLDN PAN coordinator switches from the LLDN Discovery state into the LLDN Configuration state after it did not receive an LLDN Discover Response Frame within the last *macLldnDiscoveryModeTimeout* seconds. | 256 |
| *macLldn-Coordinator* | Boolean | TRUE or FALSE | Indicates whether the LLDN device is the LLDN PAN coordinator | FALSE |
| *macSimpleAddress* | Integer | 0x00-0xff | The 8-bit address that the LLDN device uses to communicate in the LLDN. If the device is the LLDN PAN coordinator, this value shall be chosen before an LLDN is started. Otherwise, the address is allocated by a LLDN PAN coordinator during association. A value of 0xfe indicates that the LLDN device has associated but has not been allocated an address. A value of 0xff indicates that the LLDN device does not have a simple address. | 0xff |

Some MAC PIB attributes of Table 113 have a different default value in Low Latency Deterministic Networks (LLDNs). lists LLDN specific settings of these MAC PIB attributes of Table 133.

Table G.14—LLDN specific settings of MAC PIB attributes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** | **Default** |
| *macMinBE* | Integer | 0-*macMaxBE* | The minimum value of the backoff exponent (BE) in the LLDN simplified CSMA-CA algorithm, as described in G.2.3. | 3 |
| *macMaxBE* | Integer | 3–8 | The maximum value of the backoff exponent, BE, in the LLDN simplified CSMA-CA algorithm, as described in G.2.3. | 3 |
| *macMaxCSMABackoffs* | Integer | 0–5 | The maximum number of backoffs the LLDN simplified CSMA-CA algorithm will attempt before declaring a channel access failure. | 0 |

## LLDN Security

LLDN cannot be secured in this standard. LLDN uses 8-bit addresses (simple addresses). Any mode using simple addresses including LLDN shall not use security.

Data frames (Frame Type b001) and MAC Command frames (Frame Type b011) may be used within an LLDN. In this case, the Security Enabled bit of the Frame Control field of these frames shall be set to zero (no security enabled).

## LLDN PHY considerations

The LLDN specification has been developed for the 2450 MHz O-QPSK PHY. The LLDN specification is PHY-independent, in principle. For instance, it can be used with the HRP UWB PHY. However, the use of several PHYs of this standard with LLDN is not advisable, for instance, PHYs targetting a completely different application case than LLDN. There is no requirement that every PHY of this standard has to support LLDN.