**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | [] |
| Abstract | Sponsor ballot draft of the Time-slot Relaying based Link Extension  |
| Purpose | Draft standard development |
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*Insert the following to the draft*

**----------------------------------------------------------------------------------------------------------------------------**

* 1. MAC frame formats
		1. Format of individual frame types
			1. Beacon frame format
				1. Beacon frame MHR fields

5.2.2.1.1a Information Elements fields

***Insert the following new row at the end of Table 3b:***

Table 3b-EBR IEs per enabled attribute

|  |  |  |  |
| --- | --- | --- | --- |
| Attribute Request Identifier | PIB attribute | IE type | IEs to include |
| TBD | *macTRLEenabled* | Header | TRLE Descriptor (Annex S.5.1.1) |

* + 1. Information element
			1. General
			2. Header Information Elements

***Insert the following new rows in Table 4b:***

Table 4b-Element IDs, Header IEs

|  |  |  |  |
| --- | --- | --- | --- |
| Element ID | Content length | Name | Description |
| TBD | 3 | TRLE Descriptor | Defined in Annex S.5.1.1 |

* 1. MAC command frames

***Insert the following new rows in Table 5:***

Table 5-MAC Command frames

|  |  |  |  |
| --- | --- | --- | --- |
| Command frame identifier | Command name | RFD | Subclause |
| Tx | Rx |
| TBD | TRLE-Management request | X | X | Annex S.5.2.1 |
| TBD | TRLE-Management response | X | X | Annex S.5.2.2 |

6.2 MAC management service

* + 1. Communications notification primitives
			1. MLME-BEACON-NOTIFY.indication

***Insert at the end of Table 17 the following new row:***

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Type | Valid range | Description |
| TRLE Descriptor | TRLE Descriptor value | As defined in Annex S.5.1.1 | The TRLE Descriptor for the received beacon |

* 1. MAC constants and PIB attributes
		1. MAC constants
		2. MAC PIB attributes
		3. Calculating PHY dependent MAC PIB values
			1. General
			2. General MAC PIB attributes for functional organization

***Insert the following new rows at the end of Table 52a:***

Table 52a-General MAC PIB attributes for functional organization

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Attribute | Type | Range | Description | Default |
| *macRelayingMode* | Boolean | TRUE or FALSE | Indication of whether the MAC sublayer is in a relaying mode. A value of TRUE indicates that the MAC sublayer accepts only frames that satisfy the relaying-mode filtering requirements.  | Implementation specific |
| *macTRLEenabled* | Boolean | TRUE or FALSE | If TRUE, the device is using functionality specific to TRLE | Implementation specific |

***Insert after Annex R the following new annex (Annex S):***

**Annex S**

(normative)

**Time-slot Relaying based Link Extension**

S.1 General

In a star topology, the range of the network is limited by the transmission and reception range of the devices forming a link. There are occasions when a further range extension of the network may be required. An example would be when supporting a very sparse dispersion of devices beyond the radio range of a PAN coordinator to endpoint. Another example may arise when maintaining connection with an endpoint where the RF environment degrades as a result of geographic change after the initial deployment.

A PAN relay is a coordinator that relays IEEE Std 802.15.4 MAC frames either in the direction of the PAN coordinator or in the direction of a device. This annex provides specific MAC capabilities for extending the range of a link in a star network composed of the IEEE 802.15.4 beacon enabled devices or the IEEE 802.15.4 DSME enabled devices. The time-slot relaying based link extension (TRLE) PAN relays resided between the PAN coordinator and devices support transparent link connectivity without additional networking overheads to an endpoint.

Some of the capabilities provided by this annex are as follows:

* Frame filtering in relaying mode
* Frame relaying on a link between the IEEE 802.15.4 beacon enabled PAN coordinator and devices
* Management of multi-hop relaying path between the TRLE enabled PAN coordinator and devices
* Frame relaying on a TRLE multi-hop path

S.2 Link extension for a beacon-enabled PAN

The TRLE PAN relay extends the link of a beacon-enabled PAN by relaying frames at the MAC sublayer in direction to a device (i.e. outward relaying) or in direction to the PAN coordinator (i.e. inward relaying).

The TRLE PAN relay provides one-hop relaying link extension for the IEEE 802.15.4 beacon-enabled PAN. The TRLE-enabled PAN coordinator and the TRLE PAN relays provide multi-hop relaying link extension for the IEEE 802.15.4 DSME-enabled PAN.

The TRLE PAN relay may be used in several beacon enabled PAN configurations, as shown in Figure S.1: (a) beacon-enabled PAN coordinator – TRLE PAN relay – non-TRLE device, (b) TRLE-enabled PAN coordinator – multiple TRLE PAN relays – DSME-enabled device or TRLE-enabled device.



Figure S.1-Usage of the TRLE PAN relay

S.3 Link extension for the non-TRLE PAN

S.3.1 TRLE PAN relay association and disassociation

A FFD shall perform as a TRLE PAN relay, if PIB attribute *macTRLEenabled* and *macRelayingMode* are set to TRUE. A TRLE PAN relay shall associate as a coordinator with the beacon-enabled PAN, as described in 5.1.3.1.

After completing association, the next higher layer shall initiate relaying frames at the MAC sublayer by issuing the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to RELAY\_ON and SyncRelayingOffset parameter, as described in Annex S.5.3.1, that the MLME configures the following MAC PIB attribute:

* *macSyncRelayingOffset* shall be set equal to the SyncRelayingOffset parameter of the MLME-TRLE-MANAGEMENT.request primitive.

The MAC sublayer of the TRLE PAN relay shall begin relaying frames, as described in Annex S.3.3. The next higher layer shall be notified of the result of initiating the TRLE PAN relay through the MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to RELAY\_ON and status parameter, as described in Annex S.5.3.4.

If the TRLE PAN relay wants to leave the PAN, the next higher layer shall halt the relaying by issuing the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to RELAY\_OFF, as described in Annex S.5.3.1. The next higher layer shall be notified of the result of halting the TRLE PAN relay through the MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to RELAY\_OFF and status parameter, as described in Annex S.5.3.4.

After halting the relaying, the TRLE PAN relay shall disassociate with the beacon-enabled PAN, as described in 5.1.3.2.

S.3.2 Frame filtering in relaying mode

In relaying mode (i.e. *macRelayingMode* set to TRUE), the MAC sublayer shall maintain the first level of filtering and the second level of filtering described in 5.1.6.2, and accept only frames that satisfy all of the third level filtering requirements except matching of a destination address.

If the frame is valid, the MAC sublayer either passes the frame to the next higher layer or relays the frame onward according to a destination address. The frame which a destination addresses is the broadcast address shall be passed to the next higher layer and be also relayed onward.

S.3.3 One-hop relaying

The TRLE PAN relay for the IEEE 802.15.4 beacon-enabled PAN or the IEEE 802.15.4 DSME-enabled PAN provides one-hop relaying to extend the range of the link.

If a short destination address included in the frame matches *macShortAddress*, or if an extended destination address included in the frame matches *macExtendedAddress*, the frame shall be handled as per this standard for non-TRLE devices.

The frame that a destination address is the broadcast address shall be handled as per this standard for non-TRLE devices and be also relayed at the MAC sublayer.

If a short destination address included in the frame doesn’t match *macShortAddress*, or if an extended destination address included in the frame doesn’t match *macExtendedAddress*, the frame shall be relayed at the MAC sublayer.

Frames received from the PAN coordinator shall be relayed after delaying *superframe duration\*SyncRelayingOffset*, and frames received from the device shall be relayed after delaying *superframe duration\*(2(BO-SO)- SyncRelayingOffset)*, as shown in Figure S.2. The delay for relaying is determined by the TRLE PAN relay, when associating with the beacon-enabled PAN. The algorithm for choosing *SyncRelayingOffset* is outside the scope of this standard.



Figure S.2-Relaying frames for the beacon-enabled PAN coordinator and a device

S.4 Link extension for the TRLE-enabled PAN

S.4.1 TRLE-enabled PAN

The PAN coordinator of a DSME-enabled PAN shall perform as a TRLE-enabled PAN coordinator, if PIB attribute *macTRLEenabled* is set to TRUE. The TRLE-enabled PAN coordinator may provide multi-hop relaying path with the TRLE PAN relays.

Beacon frames from the TRLE-enabled PAN coordinator received by PAN relays within the transmission range of the PAN coordinator form tier 1 of the TRLE-enabled PAN. The PAN relays that are within a transmission range of the tier 1 PAN relays, but not within PAN coordinator range, form tier 2 of the TRLE-enabled PAN, and so on, as illustrated in Figure S.3. For any given PAN relay a neighboring PAN relay closer to the PAN coordinator is called an inner PAN relay and a PAN relay closer to the endpoint is called an outer PAN relay. The relaying of a TRLE-enabled PAN is limited to seven tiers.



Figure S.3-Hierarchy of relaying in the TRLE-enabled PAN

The TRLE-enabled PAN coordinator and the PAN relay use a cyclic-superframe structure. The cyclic-superframe structure is based on the DSME multi-superframe structure, as illustrated in Figure S.4.

The CAP is divided into time slots for transmitting a frame to the PAN coordinator (i.e. the prioritized device time slot) and time slots for transmitting a frame to endpoint devices (i.e. the coordinator time slot). The prioritized device time slot starts after the beacon and continues for a preset number of time slots, *macNumPrioritizedDeviceSlot*. The coordinator time slot starts after the prioritized device time slot and continues for a preset number of time slots, *macNumCoordSlot*.

The time slot in CFP is bidirectional (i.e. the bidirectional device time slot). The bidirectional device time slots for a TRLE PAN relay or TRLE-enabled device may be pre-assigned or allocated before use.



Figure S.4-Time slots in a TRLE cyclic-superframe

S.4.2 Starting a TRLE-enabled PAN

The PAN coordinator that PIB attributes *macDSMEenabled* and *macTRLEenabled* are set to TRUE shall start a DSME-enabled PAN by following the procedure described in 5.1.2.3.1.

The PAN coordinator shall be instructed to begin operating as the TRLE-enabled PAN coordinator through the use of the MLME-TRLE-MANAGEMENT.request primitive, as described in Annex S.5.3.1, with the ManagementType parameter set to START, NumPrioritizedDevice parameter, and NumCoordSlot parameter.

On receipt of this primitive, the MLME configures the following MAC PIB attributes:

* *macNumPrioritizedDevice* shall be set equal to the NumPrioritizedDevice parameter of the MLME-TRLE-MANAGEMENT.request primitive.
* *macNumCoordSlot* shall be set equal to the NumCoordSlot parameter of the MLME-TRLE-MANAGEMENT.request primitive.

After completing this, the MAC sublayer shall issue the MLME-TRLE-MANAGEMENT.confirm primitive with the ManagementType parameter set to START and a status of SUCCESS, as described in Annex S.5.3.4, and begin operating as the TRLE-enabled PAN coordinator.

The TRLE-enabled PAN is formed when the TRLE-enabled PAN coordinator advertises the presence of the TRLE-enabled PAN by sending enhanced beacon, which contains the DSME PAN descriptor IE and the TRLE descriptor IE, as defined in Annex S.5.3.1.

S.4.3 TRLE relaying path formation

A FFD that PIB attributes *macDSMEenabled*, *macTRLEenabled,* and *macRelayingMode* are set to TRUE shall perform as a TRLE PAN relay. A RFD that PIB attributes *macDSMEenabled* and *macTRLEenabled* are set to TRUE shall perform as a TRLE-enabled device.

The next higher layer of a TRLE PAN relay or TRLE-enabled device shall perform a MAC sublayer reset, by issuing the MLME-RESET.request primitive with the SetDefaultPIB parameter set to TRUE, and then complete either an active or a passive channel scan, as defined in 5.1.2.1.2. The results of the channel scan would have then been used to choose a suitable PAN and to select an inner coordinator, the TRLE-enabled PAN coordinator or an inner TRLE PAN relay, through which it wishes to associate.

Following the selection of a TRLE-enabled PAN, a TRLE PAN relay or a TRLE-enabled device shall be instructed to associate with a DSME-enabled PAN, as described in 5.1.3.1.

After completing association, the next higher layer shall instruct through the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to JOIN and TxGrade parameter set to GRADE\_0 for the TRLE PAN relay or set to GRADE\_2 for the TRLE-enabled device, as described in Annex S.5.3.1, that the MLME configures the following MAC PIB attributes:

* *macRelayingTier* shall be set equal to the SrcRelayingTier parameter of the MLME-TRLE-MANAGEMENT.request primitive.
* *macInnerRelayingOffset* shall be set equal to the InnerRelayingOffset parameter of the MLME-TRLE-MANAGEMENT.request primitive.
* *macNumBidirectionalDeviceSlot* shall be set equal to the NumBidirectionalDeviceSlot parameter of the MLME-TRLE-MANAGEMENT.request primitive.

The MAC sublayer shall initiate the joining procedure by sending a TRLE-Management request command with the Management Type field set to Join, as described in Annex S.5.2.1. The TRLE Descriptor IE shall be included in the Header IE field of the TRLE-Management request command. The TxGrade parameter of the request primitive is set to the Grade of Link Access field of the TRLE Descriptor IE. The time slot that the TRLE-Management request command will be transmitted shall be selected by the InnerRelayingOffset parameter.

When relaying a TRLE-Management request command with the Management Type field set to Join, the PAN relay collects a source address of the MHR fields and the PAN relay Address field of the TRLE Descriptor IE of the frame relayed, and updates the *macPANRelayList.*

The TRLE-enabled PAN coordinator indicates the reception of a TRLE-Management request command through the MLME-TRLE-MANAGEMENT.indication primitive with ManagementType parameter set to JOIN, as described in Annex S.5.3.2. The Grade of Link Access field of the TRLE Descriptor IE is set to the TxGrade parameter of the indication primitive.

The next higher layer of the TRLE-enabled PAN coordinator shall assign time slots in a cyclic-superframe for the bidirectional device slot and determine the relaying delay at the TRLE PAN relay requesting the TRLE path formation with information provided by the BeaconBitmap parameter and RelayingPathList parameter of indication primitive. The algorithm for choosing the relaying delay is outside the scope of this standard. If time slot is not available, the next higher layer shall issue the MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to JOIN and a status of SLOT\_FULL. If it fails to determine the relaying delay, the next higher layer shall issue the MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to JOIN and a status of RELAY\_FULL. Otherwise, the next higher layer of the TRLE-enabled PAN coordinator initiates a response using an MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to JOIN and a status of SUCCESS, as described in Annex S.5.3.3.

When the MLME of the TRLE PAN coordinator receives the MLME-TRLE-MANAGEMENT.response primitive, it generates a TRLE-Management response command with the Management Type field set to Join, as described in Annex S.5.2.2, and attempts to send command to the device requesting TRLE path formation. The time slot that the TRLE-Management response command frame will be transmitted shall be selected according the TxGrade parameter of the response primitive, as described in Annex S.4.6. The identifier of the time slot is set to the Slot ID field and the Superframe ID field of the TRLE Descriptor IE. The TxGrade parameter of the response primitive is set to the Grade of Link Access field of the TRLE Descriptor IE. The Timestamp field of the TRLE-Management response command is set to the time of the time slot specified by the Slot ID field and the Superframe ID field of the TRLE Descriptor IE. The TRLE Descriptor IE shall be included in the Header IE field of the TRLE-Management response command.

On the reception of the TRLE-Management response command, the TRLE PAN relay or TRLE-enabled device informs the next higher layer of the association response by using an MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to JOIN, as described in Annex S.5.3.4.

After completing to join on a TRLE path, the next higher layer of the TRLE PAN relay shall instruct through the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to RELAY\_ON and SyncRelayingOffset parameter, as described in Annex S.5.3.1, that the MLME configures the following MAC PIB attribute:

* *macNumPrioritizedDevice* shall be set equal to the NumPrioritizedDevice parameter of the MLME-TRLE-MANAGEMENT.request primitive.
* *macNumCoordSlot* shall be set equal to the NumCoordSlot parameter of the MLME-TRLE-MANAGEMENT.request primitive.
* *macSyncRelayingOffset* shall be set equal to the SyncRelayingOffset parameter of the MLME-TRLE-MANAGEMENT.request primitive.

The MAC sublayer of the TRLE PAN relay shall begin relaying frames, as described in Annex S.4.4. The next higher layer shall be notified of the result of initiating the PAN relay through the MLME-TRLE-MANAGEMENT.confirm primitive with the ManagementType parameter set to RELAY\_ON and status parameter, as described in Annex S.5.3.4.

If the TRLE PAN relay or TRLE-enabled device wants to leave the TRLE-enabled PAN, the next higher layer shall halt the relaying by issuing the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to RELAY\_OFF. The next higher layer shall be notified of the result of halting the relaying through the MLME-TRLE-MANAGEMENT.confirm primitive with the ManagementType parameter set to RELAY\_OFF and status parameter, as described in Annex S.5.3.4.

After halting the relaying, the next higher layer shall request through the MLME-TRLE-MANAGEMENT.request primitive with ManagementType parameter set to LEAVE and TxGrade parameter set to GRADE\_0 for the TRLE PAN relay or set to GRADE\_2 for the TRLE-enabled device, as described in Annex S.5.3.1.

The MAC sublayer of the TRLE PAN relay shall initiate the leaving procedure by sending a TRLE-Management request command with the Management Type field set to LEAVE, as described in Annex S.5.2.1, through the inner coordinator to the TRLE-enabled PAN coordinator.

The TRLE-enabled PAN coordinator indicates the reception of a TRLE-Management request command through the MLME-TRLE-MANAGEMENT.indication primitive ManagementType parameter set to LEAVE, as described in Annex S.5.3.2. The next higher layer of the TRLE PAN coordinator shall confirm that the device requesting disassociation is on a relaying path and determine whether possible to leave from the relaying path.

If it is admitted, the next higher layer of the TRLE-enabled PAN coordinator initiates a response using an MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to LEAVE and a status of SUCCESS, as described in Annex S.5.3.3. Otherwise, the status parameter of the response primitive is set to NOT\_FOUND or NOT\_CONFIRMED.

When the MLME of the TRLE PAN coordinator receives the MLME-TRLE-MANAGEMENT.response primitive, it generates a TRLE-Management response command with the Management Type field set to LEAVE, as described in Annex S.5.2.2, and attempts to send command to the device requesting.

On the reception of the TRLE-Management response command, the TRLE PAN relay or TRLE-enabled device informs the next higher layer by using an MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to LEAVE, as described in Annex S.5.3.4. The status parameter MLME-TRLE-MANAGEMENT.confirm primitive is set to the Management Status filed of the Management response command.

After completing to leave on a TRLE path, the next higher layer shall initiate to disassociate with the DSME-enabled PAN, as described in 5.1.3.2.

S.4.4 Multi-hop relaying

The TRLE-enabled PAN coordinator and TRLE PAN relays may provide multi-hop relaying to extend the range of the link.

On receipt of a frame, the MAC sublayer of a TRLE PAN relay shall perform the frame filtering, as described in Annex S.3.2.

If a short destination address included in the filtered frame matches *macShortAddress*, or if an extended destination address included in the filtered frame matches *macExtendedAddress*, the frame shall be handled as per this standard.

The frame which a destination address is the broadcast address shall be handled as per this standard and be also relayed at the MAC sublayer.

If a short destination address included in the filtered frame doesn’t match *macShortAddress*, or if an extended destination address included in the filtered frame doesn’t match *macExtendedAddress*, the frame shall be relayed at the MAC sublayer.

If the Relaying Direction field of the TRLE Descriptor IE is set to one and the Relaying Tier Identifier field is equal to *macRelayingTier-1*, the frame shall be relayed outward. If the Relaying Direction field of the TRLE Descriptor IE is set to zero and the Relaying Tier Identifier field is equal to *macRelayingTier+1*, the frame shall be relayed inward. Otherwise, the TRLE PAN relay shall discard the frame.

If the PAN relay Address field of the TRLE Descriptor IE of the frame relayed outward except a beacon doesn’t match *macShortAddress*, the TRLE PAN relay shall discard the frame. If the PAN Relay Address field of the TRLE Descriptor IE of the frame relayed inward except a TRLE-Management request command with the Management Type field set to Join doesn’t match one of the outer adjacent PAN relays in the *macPANRelayList*, the TRLE PAN relay shall discard the frame.

If the frame is the TRLE-Management request command with the Management Type field set to Join or the TRLE-Management response command with the Management Type field set to Path, the PAN relay List Count field of the Relaying Path List field is increased by one and the TRLE Descriptor IE is copied to the end of the PAN relay List field of the Relaying Path List field of the command frame.

Before relaying the frame, the TRLE Descriptor IE shall be updated. The Relaying Tier Identifier field is changed to PIB attribute *macRelayingTier*. The TRLE PAN relay Address field of a beacon or the frame relayed inward is changed to PIB attribute *macShortAddress*. The TRLE PAN relay Address field of the frame relayed outward except a beacon is changed to one of the outer adjacent PAN relays in the *macPANRelayList*, indexed by the destination address of the MHR fields. The Slot ID field and Superframe ID field are set to the time slot assigned for relaying the frame, as described in Annex S.4.6.

If the Grade of Link Access field of the TRLE Descriptor IE is set to 0b00 or 0b01 and the Frame Type field indicates a data or MAC command frame relayed inward and the AR field is set to request an acknowledgment, the MAC sublayer shall send an acknowledgment frame that a destination address is set to the TRLE PAN relay Address field of the TRLE Descriptor IE. Prior to the transmission of the acknowledgment frame, the sequence number included in the received data or MAC command frame shall be copied into the Sequence Number field of the acknowledgment frame and the TRLE Descriptor IE shall be included in the Header IE of the acknowledgment frame.

The frame is relayed either outward or inward, as shown in Figure S.5. The beacon generated by the TRLE PAN coordinator shall be relayed outward after delaying *superframe duration\*RelayingDelay*. The *RelayingDelay* is calculated as *macSyncRelayingOffset-macInnerRelayingOffset,* if *macSyncRelayingOffset* is larger than *macInnerRelayingOffset*. Otherwise, The *RelayingDelay* is calculated as *2(BO-SO)- (macInnerRelayingOffset- macSyncRelayingOffset).*

The frame received in a prioritized device time slot shall be relayed inward within the prioritized device time slot. If transmission would not be completed by the end of the prioritized device time slot, the frame shall be relayed in the prioritized device time slot of the next superframe.

The frame received in a coordinator time slot shall be relayed outward within the coordinator time slot. If transmission would not be completed by the end of the coordinator time slot, the frame shall be relayed in the coordinator time slot of the next superframe.

The frame received in a bidirectional device time slot from the inner PAN relay shall be relayed outward after delaying *superframe duration\* RelayingDelay*. The frame received from the outer PAN relay shall be relayed after delaying *superframe duration\*(2(BO-SO)- RelayingDelay).*



 Figure S.5-Synchronous multi-hop frame relaying

S.4.5 TRLE path maintenance

After starting a TRLE-enabled PAN, the PAN coordinator may need to check the status of a device, collect information on the configuration of PAN relays on the TRLE relaying paths, and maintain time-synchronization.

To search activated devices in a TRLE-enabled PAN, the next higher layer shall issue the MLME-TRLE-MANAGEMENT.request primitive with the ManagementType parameter set to HELLO and the DstAddr parameter, as described in Annex S.5.3.1. The TRLE-enabled PAN coordinator only shall be allowed to set the DstAddr parameter of the request primitive to the broadcast address.

The MAC sublayer shall send the TRLE management request command with the Management Type field set to HELLO.

The MLME shall notify the reception of a TRLE management request command through the MLME-TRLE-MANAGEMENT.indication primitive with the ManagementType parameter set to HELLO. If the destination address of the TRLE management request command is set to the broadcast address, the MAC sublayer shall relay the TRLE management request command to the outer PAN relays in the *macPANRelayList*.

The next higher layer sets the device configuration, as defined in Annex S.5.2.2.7, through the MLME-TRLE-MANAGEMENT.response primitive, defined in S.5.3.3, with the ManagementType parameter set to HELLO and the DeviceDescriptor parameter.

When the MLME receives the MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to HELLO, it generates a TRLE-Management response command with the Management Type field set to HELLO, as described in Annex S.5.2.2, and attempts to send the response command to the device requesting.

The next higher layer shall be notified a reception of a TRLE-Management response command with the Management Type field set to HELLO, through the MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to HELLO and the DeviceDescriptor parameter.

To get information on the relaying path configuration to a device, the next higher layer shall issue the MLME-TRLE-MANAGEMENT.request primitive with the ManagementType parameter set to PATH and the DstAddr parameter.

The MAC sublayer shall send the TRLE management request command with the Management Type field set to PATH, as described in Annex S.5.2.1. The request command shall be relayed to the destination device.

The MLME shall notify the reception of a TRLE management request command through the MLME-TRLE-MANAGEMENT.indication primitive with the ManagementType parameter set to PATH.

The next higher layer shall report the device configuration, as defined in Annex S.5.2.2.7, through the MLME-TRLE-MANAGEMENT.response primitive with the ManagementType parameter set to PATH and the DeviceDescriptor parameter.

When the MLME receives the MLME-TRLE-MANAGEMENT.response primitive with ManagementType parameter set to PATH, it generates a TRLE-Management response command with the Management Type field set to PATH, as described in Annex S.5.2.2, and attempts to send command to the device requesting the path configuration. The relaying path configuration is added to the Relay Path List field of the response command on relaying way back to the source device, as described in Annex S.4.4.

The next higher layer shall be notified a reception of a TRLE-Management response command with the Management Type field set to PATH, through the MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to PATH, as described in Annex S.5.3.4.

The PAN relays and end points in a TRLE-enabled PAN shall be synchronized with the time of the TRLE-enabled PAN coordinator after joining the TRLE-enabled PAN.

The TRLE-enabled PAN coordinator shall advertise the time of the TRLE-enabled PAN outward to the PAN relays and end points via the Beacon Timestamp field of the DSME PAN descriptor IE in a beacon frame. The time of a TRLE PAN relay may be distributed via the Timestamp field of the TRLE-Management request command and the TRLE-Management response command. The Timestamp field shall specify the start time of a time slot where the frame is transmitted.

The PAN relays and end points compensate for the clock drift based on the statistical variance of the difference in the real start time of a given slot and the expected start time.

The PAN relay maintains the status of the neighbored PAN relays by watching the inner PAN relay’s beacon and the outer PAN relay’s beacon.

If the PAN relay misses the inner PAN relay’s beacon for *macBeaconMissingLimit\*BI*, the PAN relay selects one of the adjacent inner PAN relays in the *macPANRelayList*, and starts to join to the TRLE-enabled PAN coordinator and also to replicate the TRLE-enabled PAN coordinator’s beacon until finishing the joining process. If the PAN relay fails to find the adjacent inner PAN relay, the PAN relay starts to search any neighbored inner PAN relay, as described in Annex S.4.3.

If the PAN relay misses the adjacent outer PAN relay’s beacon for *macBeaconMissingLimit\*BI*, the PAN relay checks the status of the adjacent outer PAN relay by sending the TRLE-Management request command with the Management Type field set to HELLO. If it is not responded, the PAN relay makes the adjacent outer PAN relay leave from the TRLE-enabled PAN by sending the TRLE-Management request command with the Management Type field set to LEAVE and the source address set to the adjacent outer PAN relay.

S.4.6 Multiple grades of link access

In a TRLE-enabled PAN, to accommodate various qualities of service requirements for relaying frames between the TRLE-enabled PAN coordinator and a TRLE PAN relay, three grades of link access are provided: grade 0 for the delay sensitive data transmission, grade 1 for the reliable data transmission, and grade 2 for the best effort data transmission.

For grade 0 link access, a device to send a frame inward shall wait the earliest prioritized device time slot. If the device fails to transmit the data in the prioritized device time slot, the device will continue trying to transmit the data in either another prioritized device time slot or a bidirectional time slot assigned to the device, whichever comes first. A device to send a frame outward shall use the earliest coordinator time slot.

For grade 1 link access, a device shall wait the earliest bidirectional time slot assigned to the device and transmits the data. If the device fails to transmit the data, the device will keep searching next available bidirectional time slots for the duration of the cyclic-superframe or will search the coming cyclic-superframe for an opportunity to transmit the data.

For grade 2 link access, a device shall wait the earliest bidirectional time slot assigned to the device and transmits the data without requiring an acknowledgment.

The frame with grade 0 or grade 1 link access shall be acknowledged hop-by-hop and end-to-end. At a TRLE PAN relay, if the Grade of Link Access field of the TRLE Descriptor IE is set to 0b00 or 0b01 and the Frame Type field indicates a data or MAC command frame relayed inward and the AR field is set to request an acknowledgment, the MAC sublayer shall send an acknowledgment frame within the same time slot in which the frame is received. If it fails to complete transmission of the acknowledgment frame before the end of the time slot, the acknowledgment frame shall send in the coordinator time slot of the following superframe.

S.5 MAC services for the TRLE-enabled PAN

S.5.1 TRLE information elements

### S.5.1.1 TRLE Descriptor IE

The TRLE Descriptor IE shall be included in enhanced beacon, data, acknowledgment, and MAC command frames that are sent in a TRLE-enabled PAN.

The TRLE Descriptor IE shall be formatted as illustrated in Figure S.6.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bits: 0-2 | 3 | 4-5 | 6-9 | 10-23 | Octets: 2 |
| Relaying Tier Identifier | Relaying Direction | Grade of Link Access | Slot ID | Superframe ID | PAN relay Address |

Figure S.6- TRLE Descriptor format

The Relaying Tier Identifier field shall be set to the identifier of relaying tier of the TRLE PAN relay by which this frame will be transmitted. A value of zero shall indicate the tier 0 where the TRLE-enabled PAN coordinator is located.

The Relaying Direction field shall be set to one if the frame is relayed outward, otherwise it is set to zero.

The Grade of Link access field shall be set to the TxGrade parameter stated in the primitive, defined in S.5.3.

The Slot ID field contains the ID of the time slot in which this frame will be transmitted.

The Superframe ID field contains the ID of the superframe in which this frame will be transmitted.

The PAN relay Address field of an inward frame or a beacon shall be set to PIB attribute *macShortAddress* of the TRLE PAN relay by which this frame will be transmitted. The PAN relay Address field of an outward frame except a beacon shall be set to one of the neighbored PAN relays in the *macPANRelayList*, indexed by the destination address of the MHR fields.

S.5.2 TRLE commands

### S.5.2.1 TRLE-Management request command

The TRLE-Management request command allows a device, which PIB attributes *macTRLEenabled* is set to TRUE, to request to join to a TRLE relaying path, or leave from the TRLE relaying path, or report relaying path information, or assign a device slot.

Only devices with a 16-bit short address less than 0xfffe shall send this command.

The TRLE-Management request command shall be formatted as illustrated in Figure S.7.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Octets: variable | 1 | 1 | 0/6 | 0/variable | 0/1 | 0/variable |
| MHR fields(refer to 5.2.2.4.1) | Command Frame Identifier(Table 5) | Management Type(Table S.1) | Timestamp | Beacon Bitmap | Number of Slots | Relaying Path List |

Figure S.7-TRLE-Management request command format

S.5.2.1.1 MHR fields

The Destination Addressing Mode and the Source Addressing Mode fields of the Frame Control field shall both be set to two (i.e., 16-bit short addressing).

The Frame Pending field of the Frame Control field shall be set to zero and ignored upon reception.

The Source PAN Identifier field shall contain the value of *macPANId*, and the Source Address field shall contain the value of *macShortAddress*.

The Destination PAN Identifier field shall contain the value of *macPANId*, and the Destination Address field shall be set to the short address of the destination device.

S.5.2.1.2 Management Type field

The Management Type field shall be set one of the values listed in Table S.1.

Table S.1- Values of the Management Type field

|  |  |
| --- | --- |
| Management Type value | Description |
|
| 0x00 | Join |
| 0x01 | Leave |
| 0x02 | Hello |
| 0x03 | Path |
| 0x04~0xff | Reserved |

S.5.2.1.3 Timestamp field

This field is valid only if the management type is 0x02 (hello) or 0x03 (path).

The Timestamp field shall contain the time, in microseconds, of the time slot in which the management request command frame will be transmitted.

S.5.2.1.4 Beacon Bitmap field

This field is valid only if the management type is 0x00 (join).

The Beacon Bitmap field is described in 5.2.4.9.3. The Beacon Bitmap field shall be set to the BeaconBitmap parameter of the MLME-TRLE-MANAGEMENT.request pritimitive.

S.5.2.1.5 Number of Slots field

This field is valid only if the management type is 0x00 (join).

The Number of Slots field shall contain the number of bidirectional device time slots that this command is requesting. The Number of Slots field shall be set to the NumBidirectionalDeviceSlot parameter of the MLME-TRLE-MANAGEMENT.request primitive.

S.5.2.1.6 Relaying Path List field

This field is valid only if the management type is 0x00 (join).

The Relaying Path List field shall be formatted as illustrated in Figure S.8.

|  |  |
| --- | --- |
| Octets: 1 | variable |
| PAN relay List Count | PAN relay List |

Figure S.8- TRLE Relaying Path Descriptor field format

The PAN relay List Count field shall contain the number of the PAN relays in the PAN relay List field.

The PAN relay List field shall contain the TRLE descriptors on a TRLE path, as defined in Annex S.5.1.1.

S.5.2.2 TRLE-Management response command

The TRLE-Management response command allows the TRLE-enabled PAN coordinator or the TRLE PAN relay to communicate the results of a request to join to a TRLE relaying path, or leave from the TRLE relaying path, or report relaying path information, or assign a device slot.

Only devices with a 16-bit short address less than 0xfffe shall send this command.

The TRLE-Management response command shall be formatted as illustrated in Figure S.9.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Octets: variable | 1 | 1 | 1 | 0/6 | 0/2 | 0/variable | 0/variable | 0/variable |
| MHR fields(refer to 5.2.2.4.1) | Command Frame Identifier(defined in Table 5) | Management Type(defined in Annex S.5.2.1.2) | Management Status | Timestamp | Sync Relaying Offset | Bidirectional Device Slot List | Device Descriptor | Relaying Path List(defined in Annex S.5.2.1.7) |

Figure S.9-TRLE-Management response command format

S.5.2.2.1 MHR fields

The Destination Addressing Mode and the Source Addressing Mode fields of the Frame Control field shall both be set to two (i.e., 16-bit short addressing).

The Frame Pending field of the Frame Control field shall be set to zero and ignored upon reception.

The Source PAN Identifier field shall contain the value of *macPANId*, and the Source Address field shall contain the value of *macShortAddress*.

The Destination PAN Identifier field shall contain the value of *macPANId*, and the Destination Address field shall be set to the short address of the destination device.

S.5.2.2.2 Management Type field

The Management Type field is described in Annex S.5.2.1.2.

S.5.2.2.3 Management Status field

The Management Status field shall be set to the status parameter of the MLME-TRLE-MANAGEMENT.response primitive.

S.5.2.2.4 Timestamp field

This field is valid only if the management type is 0x00 (join).

The Timestamp field shall contain the time, in microseconds, of the time slot in which the management response command frame will be transmitted.

S.5.2.2.5 Sync Relaying Offset field

This field is valid only if the management type is 0x00 (join).

The Sync Relaying Offset field shall contain the relaying delay of a PAN relay’s cyclic-superframe compared to the TRLE-enabled PAN coordinator’s cyclic-superframe, which is specified in the number of superframe.

The Sync Relaying Offset field shall be set to the SyncRelayingOffset parameter of the MLME-TRLE-MANAGEMENT.response primitive.

S.5.2.2.6 Bidirectional Device Slot List field

This field is valid only if the management type is 0x00 (join).

The Bidirectional Device Slot List field shall be set to the BidirectionalDeviceSlotList parameter of the MLME-TRLE-MANAGEMENT.response primitive, as defined in S.5.3.3.

The Bidirectional Device Slot List field shall be formatted as illustrated in Figure S.10.

|  |  |
| --- | --- |
| Octets: 1 | variable |
| Bidirectional Device Slot List Count | Bidirectional Device Slot |

Figure S.10- Bidirectional Device Slot List field format

The Bidirectional Device Slot List Count field shall contain the number of the Bidirectional Device Slot Descriptor in the Bidirectional Device Slot List field.

The Bidirectional Device Slot field shall be formatted as illustrated in Figure S.11.

|  |  |
| --- | --- |
| Octets: 1 | 2 |
| Slot ID | Superframe ID |

Figure S.11- Bidirectional Device Slot Descriptor format

The Slot ID field contains the ID of the time slot of the superframe in which a bidirectional device time slot is assigned. The slot ID is the sequence number of the time slot in a superframe beginning from zero.

The Superframe ID field contains the ID of the superframe in which a bidirectional device time slot is assigned. The superframe ID is the sequence number of the superframe in a cyclic-superframe beginning from zero.

S.5.2.2.7 Device Descriptor field

This field is valid only if the management type is 0x02 (hello) or 0x03(path).

The Device Descriptor field shall be set to the DeviceDescriptor parameter of the MLME-TRLE-MANAGEMENT.response primitive (refer to S.5.3.3).

The Device Descriptor field shall be formatted as illustrated in Figure S.12.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Octets: 2 | 1 | 2 | 2 | 2 | 3 | variable |
| Device Address | Relaying Tier Identifier | Sync Relaying Offset | Inner PAN relay Address | Inner Relaying Offset | Primary Device Slot Descriptor | Beacon Bitmap(defined in 5.2.4.9.3) |

Figure S.12- TRLE Device Descriptor format

The Device Address field shall be set to the short address of the TRLE device that this command is requesting.

The Relaying Tier Identifier field shall contain the identifier of relaying tier of the TRLE device that this command is requesting.

The Sync Relaying Offset field shall contain the relaying delay of the TRLE device that this command is requesting.

The Inner PAN relay Address field shall be set to the short address of the inner PAN relay of the TRLE device that this command is requesting.

The Inner Relaying Offset field shall contain the relaying delay of the inner PAN relay of the TRLE device that this command is requesting.

The Primary Device Slot Descriptor field shall contain the primary bidirectional device slot of the TRLE device that this command is requesting, and shall be formatted as illustrated in Figure S.11.

The Beacon Bitmap field is described in 5.2.4.9.3.

S.5.2.2.8 Relaying Path List field

This field is valid only if the management type is 0x03 (path).

The Relaying Path List field is described in Annex S.5.2.1.6.

S.5.3 Primitives for managing the TRLE-enabled PAN

### S.5.3.1 MLME-TRLE-MANAGEMENT.request

The MLME-TRLE-MANAGEMENT.request primitive requests to start a TRLE-enabled PAN, or join to a TRLE relaying path, or leave from the TRLE relaying path or report relaying path information.

The semantics of this primitive are:

MLME-TRLE-MANAGEMENT.request (

 ManagementType,

 DstAddrMode,

 DstAddr,

TxGrade,

NumPrioritizedDeviceSlot,

NumCoordSlot,

NumBidirectionalDeviceSlot,

SrcRelayingTier,

BeaconBitmap,

InnerRelayingOffset,

SyncRelayingOffset,

SecurityLevel,

KeyIdMode,

KeySource,

KeyIndex

 )

The primitive parameters are defined in Table S.3

Table S.3- MLME-TRLE-MANAGEMENT.request parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Type | Valid range | Description |
| ManagementType | Enumeration | START, JOIN, LEAVE, RELAY\_ON, RELAY\_OFF, HELLO, PATH | The type of TRLE-enabled PAN management to be performed.START = 0, JOIN = 1, LEAVE = 2, RELAY\_ON = 3, RELAY\_OFF = 4, HELLO = 5, PATH = 6 |
| DstAddrMode | Enumeration | NO\_ADDRESS,SHORT\_ADDRESS,EXTENDED\_ADDRESS | The destination addressing mode for this primitive. |
| DstAddr  | Deviceaddress | As specified by the DstAddrMode parameter | The individual device address of the device for which the frame was intended. |
| TxGrade | Enumeration | GRADE\_0,GRADE\_1,GRADE\_2 | The grade of link access to be used.GRADE\_0 = 0, GRADE\_1 = 1, GRADE\_2 = 2 |
| NumPrioritizedDevice | Integer | 1-6 | The number of time slots in a superframe assigned as the prioritized device slots. |
| NumCoordSlot | Integer | 1-6 | The number of time slots in a superframe assigned as the coordinator slots. |
| NumBidirectionalDeviceSlot | Integer | 1-12 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slot. |
| SrcRelayingTier | Integer | 0-7 | The identifier of the relaying tier in which a device is placed. The relaying tier of the PAN coordinator is zero. |
| BeaconBitmap | Bitmap | Defined in 5.2.4.9.3 | The beacon bitmap as specified in the received enhanced beacon frame. |
| InnerRelayingOffset | Integer | 0x0000-0x7fff | The index of the superframe at which the inner PAN relay starts a cyclic-superframe. If inner PAN relay of a device is the TRLE-enabled PAN coordinator, the InnerRelayingOffset of the device is zero. |
| SyncRelayingOffset | Integer | 0x0000-0x7fff | The index of the superframe at which a device starts a cyclic-superframe. The SyncRelayingOffset of the PAN coordinator is zero. |
| SecurityLevel | Integer | As defined in Table 46 | As defined in Table 46 |
| KeyIdMode | Integer | As defined in Table 46 | As defined in Table 46 |
| KeySource | Set of octets | As defined in Table 46 | As defined in Table 46 |
| KeyIndex | Integer | As defined in Table 46 | As defined in Table 46 |

The MLME-TRLE-MANAGEMENT.request primitive may be used by TRLE-enabled PAN management layer to establish, or operate or maintain a TRLE relaying path.

When ManagementType is set to START, all parameters except NumPrioritizedDevice and NumCoordSlot shall be ignored, and the MAC sublayer shall attempt to update the cyclic-superframe specification and begin the transmission of the TRLE Relaying IE in enhanced beacon.

When ManagementType is set to JOIN, all parameters except DstAddrMode, DstAddr, TxGrade, SrcRelayingTier, InnerRelayingOffset, BeaconBitmap, and NumBidirectionalDeviceSlot shall be ignored, and the MAC sublayer shall attempt to update the appropriate MAC PIB attributes, as described in Annex S.4.3, and generate a management request command with Management Type field set to JOIN, as defined in Annex S.5.2.1.

When ManagementType is set to LEAVE, all parameters except DstAddrMode, DstAddr, and TxGrade shall be ignored, and the MAC sublayer shall attempt to generate a management request command with Management Type field set to LEAVE, as defined in Annex S.5.2.1.

When ManagementType is set to RELAYING\_ON, all parameters except SyncRelayingOffset shall be ignored, and the MAC sublayer shall begin relaying frames, as described in Annex S.4.4.

When ManagementType is set to RELAYING\_OFF, all parameters shall be ignored, and the MAC sublayer shall halt to relay frames.

When ManagementType is set to HELLO, all parameters except DstAddrMode and DstAddr shall be ignored, and the MAC sublayer shall attempt to generate a management request command with Management Type field set to HELLO, as defined in Annex S.5.2.1.

When ManagementType is set to PATH, all parameters except DstAddrMode and DstAddr shall be ignored, and the MAC sublayer shall attempt to generate a management request command with Management Type field set to PATH, as defined in Annex S.5.2.1.

The TRLE Management request command frame is relayed to the DstAddr with the grade of link access specified in TxGrade.

Typically, the management request command should not be implemented using security. However, if the device shares a key with the coordinator, then security may be specified.

S.5.3.2 MLME-TRLE-MANAGEMENT.indication

The MLME-TRLE-MANAGEMENT.indication is used to indicate the reception of a TRLE Management Request command.

The semantics of this primitive are:

MLME-TRLE-MANAGEMENT.indication (

 ManagementType,

 SrcAddrMode,

 SrcAddr,

TxGrade

Timestamp,

BeaconBitmap

NumDeviceSlot,

RelayingPathList,

SecurityLevel,

KeyIdMode,

KeySource,

KeyIndex

 )

The primitive parameters are defined in Table S.4.

Table S.4- MLME-TRLE-MANAGEMENT.indication parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Type | Valid range | Description |
| ManagementType | Enumeration | START, JOIN, LEAVE, RELAY\_ON, RELAY\_OFF, HELLO, PATH | The type of TRLE-enabled PAN management to be performed.START = 0, JOIN = 1, LEAVE = 2, RELAY\_ON = 3, RELAY\_OFF = 4, HELLO = 5, PATH = 6 |
| SrcAddrMode  | Enumeration | NO\_ADDRESS,SHORT\_ADDRESS,EXTENDED\_ADDRESS | The source addressing mode for this primitive |
| SrcAddr  | Deviceaddress | As specified by theSrcAddrMode parameter | The individual device address of the device for which the frame was generated. |
| TxGrade | Enumeration | GRADE\_0,GRADE\_1,GRADE\_2 | The grade of link access to be used.GRADE\_0 = 0, GRADE\_1 = 1, GRADE\_2 = 2 |
| Timestamp | Integer | 0x000000–0xffffff | The time, in symbols, at which the Management request command was transmitted.The symbol boundary is described by *macSyncSymbolOffset* as defined in Table 86.This is a 24-bit value, and the precision of this value shall be a minimum of 20 bits, with the lowest 4 bits being the least significant. |
| BeaconBitmap | Bitmap | Defined in 5.2.4.9.3 | The beacon bitmap as specified in the received enhanced beacon frame. |
| NumDeviceSlot | Integer | 0x00-0x5 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slots. |
| RelayingPathList | Set of octets of variable length | Refer to Annex S.5.2.1.6 | The relaying information on a TRLE relaying path. |
| SecurityLevel | Integer | As defined in Table 48 | As defined in Table 48 |
| KeyIdMode | Integer | As defined in Table 48 | As defined in Table 48 |
| KeySource | Set of octets | As defined in Table 48 | As defined in Table 48 |
| KeyIndex | Integer | As defined in Table 48 | As defined in Table 48 |

This primitive is generated by the MLME of a device and issued to its next higher layer upon the reception of a TRLE Management request command frame.

On receipt of the MLME-TRLE-MANAGEMENT.indication primitive, the higher layer is notified of the reception of a TRLE Management request command frame.

When ManagementType is set to JOIN, all parameters except SrcAddrMode, SrcAddr, TxGrade, BeaconBitmap, NumBidirectionalDeviceSlot, and RelayingPathList shall be ignored.

When ManagementType is set to LEAVE, all parameters except SrcAddrMode, SrcAddr, and TxGrade shall be ignored.

When ManagementType is set to HELLO, all parameters except SrcAddrMode, SrcAddr, TxGrade, and Timestamp shall be ignored.

When ManagementType is set to PATH, all parameters except SrcAddrMode, SrcAddr, TxGrade, and Timestamp shall be ignored.

S.5.3.3 MLME-TRLE-MANAGEMENT.response

This primitive allows the next higher layer of a device to respond to the MLME-TRLE-MANAGEMENT.indication primitive.

The semantics of this primitive are:

MLME-TRLE-MANAGEMENT.response (

 ManagementType,

 DstAddrMode,

 DstAddr,

TxGrade,

 status,

NumPrioritizedDeviceSlot,

NumCoordSlot,

NumBidirectionalDeviceSlot,

SyncRelayingOffset,

BidirectionalDeviceSlotList,

DeviceDescriptor,

 RelayingPathList,

SecurityLevel,

KeyIdMode,

KeySource,

KeyIndex

 )

The primitive parameters are defined in Table S.5

Table S.5- MLME-TRLE-MANAGEMENT.response parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Type | Valid range | Description |
| ManagementType | Enumeration | START, JOIN, LEAVE, RELAY\_ON, RELAY\_OFF, HELLO, PATH | The type of TRLE-enabled PAN management to be performed.START = 0, JOIN = 1, LEAVE = 2, RELAY\_ON = 3, RELAY\_OFF = 4, HELLO = 5, PATH = 6 |
| DstAddrMode  | Enumeration | NO\_ADDRESS,SHORT\_ADDRESS,EXTENDED\_ADDRESS | The destination addressing mode for this primitive |
| DstAddr  | Deviceaddress | As specified by theDstAddrMode parameter | The individual device address of the device for which the frame was intended. |
| TxGrade | Enumeration | GRADE\_0,GRADE\_1,GRADE\_2 | The grade of link access to be used |
| status | Enumeration | As defined in Annex S.5.3.4. | The status of the management attempt |
| NumCoordSlot | Integer | 1-6 | The number of time slots in a superframe assigned as the coordinator slots. |
| NumBidirectionalDeviceSlot | Integer | 1-6 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slot. |
| NumDeviceSlot | Integer | 1-12 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slots. |
| SyncRelayingOffset | Integer | 0x0000-0x7fff | The index of the superframe at which a device starts a cyclic-superframe. The SyncRelayingOffset of the PAN coordinator is zero. |
| BidirectionalDeviceSlotList | Set of Octets of variable length | Refer to Annex S.5.2.2.6 | The set of bidirectional device time slot to be allocated for the device |
| SecurityLevel | Integer | As defined in Table 46 | As defined in Table 46 |
| KeyIdMode | Integer | As defined in Table 46 | As defined in Table 46 |
| KeySource | Set of octets | As defined in Table 46 | As defined in Table 46 |
| KeyIndex | Integer | As defined in Table 46 | As defined in Table 46 |

On receipt of the MLME-TRLE-MANAGEMENT.response primitive, the MLME of the device shall generate a TRLE Management response command frame.

When ManagementType is set to JOIN, all parameters except DstAddrMode, DstAddr, TxGrade, status, NumPrioritizedDeviceSlot, NumCoordSlot, SyncRelayingOffset, NumBidirectionalDeviceSlot, and BidirectionalDeviceSlotList shall be ignored, and the MAC sublayer shall generate a management response command with Management Type field set to JOIN, as defined in Annex S.5.2.2.

When ManagementType is set to LEAVE, all parameters except DstAddrMode, DstAddr, TxGrade, and status shall be ignored, and the MAC sublayer shall generate a management response command with Management Type field set to LEAVE, as defined in Annex S.5.2.2.

When ManagementType is set to HELLO, all parameters except DstAddrMode, DstAddr, TxGrade, status, and DeviceDescriptor shall be ignored, and the MAC sublayer shall generate a management response command with Management Type field set to HELLO, as defined in Annex S.5.2.2.

When ManagementType is set to PATH, all parameters except DstAddrMode, DstAddr, TxGrade, status, and DeviceDescriptor shall be ignored, and the MAC sublayer shall generate a management response command with Management Type field set to PATH, as defined in Annex S.5.2.2.

S.5.3.4 MLME-TRLE-MANAGEMENT.confirm

The MLME-TRLE-MANAGEMENT.confirm primitive reports the result of the TRLE management request.

The semantics of this primitive are:

MLME-TRLE-MANAGEMENT.confirm (

 ManagementType,

 SrcAddrMode,

 SrcAddr,

status,

Timestamp,

NumPrioritizedDeviceSlot,

NumCoordSlot,

SyncRelayingOffset,

NumBidirectionalDeviceSlot,

BidirectionalDeviceSlotList

 DeviceDescriptor,

 RelayingPathList,

SecurityLevel,

KeyIdMode,

KeySource,

KeyIndex

 )

The primitive parameters are defined in Table S.6

Table S.6- MLME-TRLE-MANAGEMENT.confirm parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Type | Valid range | Description |
| ManagementType | Enumeration | START, JOIN, LEAVE, RELAY\_ON, RELAY\_OFF, HELLO, PATH | The type of TRLE-enabled PAN management to be performed.START = 0, JOIN = 1, LEAVE = 2, RELAY\_ON = 3, RELAY\_OFF = 4, HELLO = 5, PATH = 6 |
| SrcAddrMode  | Enumeration | NO\_ADDRESS,SHORT\_ADDRESS,EXTENDED\_ADDRESS | The source addressing mode for this primitive |
| SrcAddr  | Deviceaddress | As specified by the SrcAddrMode parameter | The individual device address of the device for which the frame was generated. |
| status | Enumeration | SUCCESS,INVALID\_PARAMETER,CHANNEL\_ACCESS\_FAILURE, FRAME\_TOO\_LONG, SLOT\_FULL, RELAY\_FULL, NOT\_FOUND, NOT\_CONFIRMED,UNAVAILABLE\_KEY,UNSUPPORTED\_SECURITY, | The result of the management request attempt |
| Timestamp | Integer | 0x000000–0xffffff | The time, in symbols, at which the Management request command was transmitted.The symbol boundary is described by *macSyncSymbolOffset* as defined in Table 86.This is a 24-bit value, and the precision of this value shall be a minimum of 20 bits, with the lowest 4 bits being the least significant. |
| NumPrioritizedDevice | Integer | 1-6 | The number of time slots in a superframe assigned as the prioritized device slots. |
| NumCoordSlot | Integer | 1-6 | The number of time slots in a superframe assigned as the coordinator slots. |
| NumBidirectionalDeviceSlot | Integer | 1-12 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slot. |
| SyncRelayingOffset | Integer | 0x0000-0x7fff | The index of the superframe at which a device starts a cyclic-superframe. The SyncRelayingOffset of the PAN coordinator is zero. |
| BidirectionalDeviceSlotList | Set of Octets of variable length | Refer to Annex S.5.2.2.6 | The set of bidirectional device time slot to be allocated for the device |
| DeviceDescriptor | Set of Octets | Refer to Annex S.5.2.2.7 | The relaying specification of a device |
| RelayingPathList | Set of octets of variable length | Refer to Annex S.5.2.1.6 | The relaying information on a TRLE relaying path. |
| SecurityLevel | Integer | As defined in Table 46 or Table 48 | If the primitive were generated following failed outgoing processing of a management request command, then it is as defined in Table 46. If the primitive were generated following receipt of a management response command, then it is as defined in Table 48. |
| KeyIdMode | Integer | As defined in Table 46 or Table 48 | If the primitive were generated following failed outgoing processing of a management request command, then it is as defined in Table 46. If the primitive were generated following receipt of a management response command, then it is as defined in Table 48. |
| KeySource | Set of octets | As defined in Table 46 or Table 48 | If the primitive were generated following failed outgoing processing of a management request command, then it is as defined in Table 46. If the primitive were generated following receipt of a management response command, then it is as defined in Table 48. |
| KeyIndex | Integer | As defined in Table 46 or Table 48 | If the primitive were generated following failed outgoing processing of a management request command, then it is as defined in Table 46. If the primitive were generated following receipt of a management response command, then it is as defined in Table 48. |

The MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to START or RELAY\_ON, or RELAY\_OFF is generated by the MAC sublayer entity in response to an MLME-TRLE-MANAGEMENT.request primitive.

When ManagementType is set to START or RELAY\_ON, or RELAY\_OFF, all parameters except status shall be ignored.

On receipt of the MLME-TRLE-MANAGEMENT.confirm primitive with ManagementType parameter set to JOIN or LEAVE or HELLO or PATH, or TIME, the higher layer is notified of the reception of a TRLE Management response command frame.

When ManagementType is set to JOIN, all parameters except SrcAddrMode, SrcAddr, status, NumPrioritizedDeviceSlot, NumCoordSlot, SyncRelayingOffset NumBidirectionalDeviceSlot, and BidirectionalDeviceSlotList shall be ignored.

When ManagementType is set to LEAVE, all parameters except SrcAddrMode, SrcAddr, and status shall be ignored.

When ManagementType is set to HELLO, all parameters except SrcAddrMode, SrcAddr, status, and DeviceDescriptor shall be ignored.

When ManagementType is set to PATH, all parameters except SrcAddrMode, SrcAddr, status, DeviceDescriptor, and RelayingPathList shall be ignored.

The MLME-TRLE-MANAGEMENT.confirm primitive returns a status of either SUCCESS or the appropriate error code as follows:

* CHANNEL\_ACCESS\_FAILURE – The transmission of the coordinator realignment frame failed.
* FRAME\_TOO\_LONG – The length of the beacon frame exceeds *aMaxPHYPacketSize*.
* SLOT\_FULL – The allocation of the bidirectional device time slot failed.
* RELAY\_FULL – The allocation of the superframe for relaying a beacon failed.
* NOT\_FOUND – The device requesting not be found
* NOT\_CONFIRMED – The request to leave from a relaying path is not admitted.
* A security error code, as defined in 7.2.

S.5.4 TRLE specific MAC PIB attributes

The attributes contained in the MAC PIB for TRLE are presented in Table S.7.

Table S.7-TRLE specific MAC PIB attributes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Attribute | Type | Range | Description | Default |
| *macNumPrioritizedDeviceSlot* | Integer | 1-6 | The number of time slots in a superframe assigned as the prioritized device slots. | 3 |
| *macNumCoordSlot* | Integer | 1-6 | The number of time slots in a superframe assigned as the coordinator slots. | 3 |
| *macNumBidirDeviceSlot* | Integer | 1-12 | The number of time slots in a cyclic-superframe assigned as the bidirectional device slots. | 1 |
| *macRelayingTier* | Integer | 0-7 | The identifier of the relaying tier in which a device is placed. The relaying tier of the PAN coordinator is zero. | Implementation specific |
| *macInnerRelayingOffset* | Integer | 0x0000-0x7fff | The relaying delay of an inner PAN relay’s cyclic-superframe compared to the TRLE-enabled PAN coordinator’s cyclic-superframe, which is specified in the number of superframe.If inner PAN relay of a device is the TRLE-enabled PAN coordinator, the *macInnerRelayingOffset* of the device is zero. | Implementation specific |
| *macSyncRelayingOffset* | Integer | 0x0000-0x7fff | The relaying delay of a PAN relay’s cyclic-superframe compared to the TRLE-enabled PAN coordinator’s cyclic-superframe, which is specified in the number of superframe.The *macSyncRelayingOffset* of the PAN coordinator is zero. | Implementation specific |
| *macPANRelayList* | PAN Relay List | PAN Relay List | The list of the neighbored PAN relays, which inform the end devices reached by the PAN relay. | Implementation specific |
| *macBeaconMissingLimit* | Integer | 0-7 | The number of beacon which is missed before starting link recovery processing. | Implementation specific |