**IEEE P802.15**

**Wireless Personal Area Networks**

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**6.2.6.3 Links**

Figure 22 illustrates an example of nodes communicating in a sample three-timeslot slotframe. Nodes A and B communicate during timeslot 0, nodes B and C communicate during timeslot 1, and timeslot 2 is not being used. Every three timeslots, the schedule repeats, but note that ASN increments continuously. The pairwise assignment of a directed communication between devices in a given timeslot on a given *macChannelOffset* is a link. Physical channel, CH, in a link is made according to the following formula:

CH = *macHoppingSequenceList* [(*macASN* + *macChannelOffset* ~~channelOffset~~) % *macHoppingSequenceLength*]



Use of a *macChannelOffset* allows for different channels to be used at a given *macASN* for a given *macHoppingSequenceList*. There are *macNumberOfChannels* channel~~Offsets~~ offsets that will result in a unique channel for that combination of *macASN* and *macHoppingSequenceList*.

**6.2.6.4 Multiple slotframes**

A given network using timeslot-based access may contain several concurrent slotframes of different sizes. Multiple slotframes may be used to define a different communication schedule for various groups of nodes or to run the entire network at different duty cycles by giving some devices many active timeslots in a slotframe, and others few or none.

A network device may participate in one or more slotframes simultaneously, and not all devices need to participate in all slotframes. By configuring a network device to participate in multiple overlapping slotframes of different sizes, it is possible to establish different communication schedules and connectivity matrices that all work at the same time.

Slotframes can be added, removed, and modified while the network is running. Even though this is the case, all slotframes are aligned to timeslot boundaries, and timeslot 0 of the first repetition of every slotframe is projected back to *macASN* = 0, which is determined by the PAN coordinator (or other network device that starts the network). Because of this, timeslots in different slotframes are always aligned, even though the beginning and end of a particular repetition of that slotframe may not be as illustrated in [Figure 23.](#bookmark2) When, for any given timeslot, a device has links in multiple slotframes, transmissions take precedence over receives, and lower *macSlotframeHandle* slotframes takes precedence over higher *macSlotframeHandle* slotframes.



**6.3.6 TSCH PAN formation**

A TSCH PAN is formed when a device, ~~usually~~ for example the PAN coordinator, advertises the presence of the network by sending Enhanced Beacons upon receipt of a MLME-BEACON.request from a higher layer. In a TSCH PAN the Enhanced Beacons contain the following IEs:

* TSCH Synchronization IE, containing timing information so new devices can synchronize to the net- work, as described in 7.4.4.2.
* Channel hopping IE, containing channel hopping information, as described in 6.2.10 and 7.4.4.31.
* TSCH Timeslot IE, containing timeslot information describing when to expect a frame to be transmitted and when to send an acknowledgment, as described in 7.4.4.4.
* TSCH Slotframe and Link IE containing initial link and slotframe information so new devices know when to listen for transmissions from the advertising device and when they can transmit to the advertising device, as described in 7.4.4.3.

The device wishing to join a TSCH network begins passively (preferred) or actively scanning for the network as the result of receiving an MLME-SCAN.request from a higher layer. Once the listening device has heard a valid Enhanced Beacon, it generates an MLME-BEACON-NOTIFY.indication to a higher layer. The higher layer may ~~may~~ wait for additional MLME-BEACON-NOTIFY.indication primitives before selecting a TSCH network based upon the value of the Join Metric ~~Priority~~ field in the TSCH Synchronization IE. The higher layer may initialize the slotframe and links contained in the Enhanced Beacon from the preferred TSCH network and switch the device into TSCH mode with a MLME-TSCH-MODE.request.

NOTE: A lower value of join metric ~~join priority~~ indicates that connection to the beaconing device is a shorter route distance to ~~the~~ a network root, e.g. a PAN coordinator.

At this point the device is synchronized to the network and may optionally send in an Association Request command. If the device uses association, it may request a short address. The sequence of messages exchanged to synchronize a device to the networks is shown in Figure 33, and the process of synchronization is described in 6.5.3.

Typically at this point, depending upon the application, the device will go through a procedure to allocate additional communication resources (slotframes and links) to the joining device. This procedure may include a security handshake to mutually authenticate the joining device, configure encryption keys, and configure routing information. The mechanism and rules for setting up these additional communication links ~~and configure other policies~~ would normally be defined in a higher layer standard—the content of these messages is beyond the scope of this document.

Once synchronized and configured by a higher layer to do so, all FFDs that are already part of the network may send Enhanced Beacon frames announcing the presence of the network. The advertising rate and content is configured by a higher layer as appropriate to the density of devices, the desired rate of network formation, and the energy devoted to network formation.

Figure 33—Message sequence chart for TSCH procedure to find an advertising device

After joining, the device may receive additional slotframes and links from a higher layer management entity or peer ~~as required by the application~~, or the device may be instructed to remove certain slotframes and links

~~obtained from the Enhanced Beacon~~.

**7.4.4.2 TSCH Synchronization IE**

The TSCH Synchronization IE Content field shall be formatted as illustrated in Figure 134.

|  |  |
| --- | --- |
| Octets: 5 | 1 |
| ASN | Join Metric ~~Priority~~ |

Figure 134—TSCH Synchronization IE Content field format

The ASN field contains the ASN corresponding to the timeslot in which the enhanced beacon is sent. The ASN is used as the Frame Counter for security operations if enabled.

The Join ~~Priority~~ Metric field is an unsigned integer and shall be set to *macJoinMetric ~~macJoinPriority~~*.

**7.4.4.3 TSCH Slotframe and Link** **IE**

The TSCH Slotframe and Link IE Content field shall be formatted as illustrated in Figure 135.

|  |  |  |  |
| --- | --- | --- | --- |
| Octets: 1 | variable | … | variable |
| Number of Slotframes | Slotframe Descriptor 1 | … | Slotframe Descriptor *n* |

Figure 135—TSCH Slotframe and Link IE Content field format

The Number of Slotframes field is set to the total number of Slotframe Descriptor fields IE.

The Slotframe Descriptor field(s) shall be formatted as illustrated in Figure 136.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Octets: 1 | 2 | 1 | 5 | … | 5 |
| Slotframe handle | Slotframe size | Number of Links | Link Information 1 | … | Link Information *m* |

Figure 136—Slotframe Descriptor field format

The Slotframe Handle field shall be set to the *macSlotframeHandle* from *macSlotframeTable* for this slotframe.

The Slotframe Size field is the size of the slotframe in number of timeslots and shall be set to the corresponding *macSlotframeSize* from *macSlotframeTable*.

The Number of Links field shall be set to the number of links that belong to the slotframe identified by the Slotframe Handle field.

The Link Information field shall be formatted as illustrated in Figure 137.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Octets: 2 | 2 | 1 |
| Timeslot | Channel Offset | Link Options |

Figure 137—Link Information field format

The Timeslot field shall be set to *macTimeslot*.

The Channel Offset Information field shall be set to *macChannelOffset*.

The Link Options field shall be formatted as illustrated in Figure 138.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bits: 0 | 1 | 2 | 3 | 4 | 5-7 |
| TX Link | RX Link | Shared Link | Timekeeping | Priority | Reserved |

Figure 138—Link Options field format

~~RX links shall have the Timekeeping field set to one.~~

~~If the TX Link field is set to one, the RX Link field and Shared Link fields shall be set to zero.~~

The Link Options field ~~indicates whether this link is a TX link, an RX link, or a SHARED TX link, and~~

~~whether the device to which it is being linked is to be used for clock synchronization. The field~~ shall be set to *macLinkOptions* within the link table for the receiving device. SHARED TX links (b0 and b2 are set to 1) are used for a joining device to send an Association Request command or other higher layer message. RX links (b1 set to 1) are used for a joining device to receive an Association Response command or other higher layer message from an advertising device (i.e., a device sending Enhanced Beacons with TSCH information). RX links shall have

the Timekeeping linkOptions bit set. It is possible for one link to be used as both SHARED TX and RX link (b0, b1, and b2 are set to 1).

**8.2.20.3 MLME-SET-LINK.request**

The MLME-SET-LINK.request primitive requests to add a new link, or delete or modify an existing link at the MAC sublayer. The SlotframeHandle and LinkHandle are supplied by a higher layer.

The semantics of this primitive are:

MLME-SET-LINK.request (

Operation,

LinkHandle,

SlotframeHandle, Timeslot,

ChannelOffset,

~~TxLink~~ LinkOptions,

~~RxLink~~

~~SharedLink~~, ~~TimekeepingLink~~, LinkType,

NodeAddr

)

The primitive parameters are defined in Table 103.

Table 103—MLME-SET-LINK.request parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
| Operation | Enumer-ation | ADD\_LINK, DELETE\_LINK, MODIFY\_LINK | Type of link management operation to be performed. |
| LinkHandle | Integer | 0x0000–0xffff | Unique identifier, local to specified slotframe, for the link, as described in Table 137. |
| Slotframe- Handle | Integer | 0x00–0xff | The slotframe handle of the slotframe to which the link is associated. |
| Timeslot | Integer | 0x0000–0xffff | Timeslot of the link to be added, as described in 6.2.6. |
| Channel- Offset | Integer | As defined in 6.2.6.3 | The Channel offset of the link  |

|  |  |  |  |
| --- | --- | --- | --- |
| ~~TxLink~~LinkOptions | ~~Boolean~~Bitmap | ~~TRUE, FALSE~~0x00–0xff | ~~Set to TRUE if it is a TX link~~ ~~and set to FALSE if it is an RX~~ ~~link~~b0 = Transmit, b1 = Receive, b2 = Shared, b3= Timekeeping,b4=Priority, b5–b7 reserved. |
| ~~RxLink~~ | ~~Boolean~~ | ~~TRUE, FALSE~~ | ~~Set to TRUE if it is an RX link, otherwise set to FALSE as described in Table 137.~~ |
| ~~SharedLink~~ | ~~Boolean~~ | ~~TRUE, FALSE~~ | ~~Set to TRUE if the link is a shared link.~~ |
| **Name** | **Type** | **Valid range** | **Description** |
| ~~TimekeepingLink~~ | ~~Boolean~~ | ~~TRUE, FALSE~~ | ~~Indicates if the link is to be used for clock synchronization. If the RxLink is TRUE TxLink is FALSE, then this shall be set to TRUE This parameter is ignored if TxLink is TRUE.~~  |
| LinkType | Enumera-tion | ADVERTISE, NORMAL | Set to ADVERTISE if it is an Advertising link, otherwise set to NORMAL. |
| NodeAddr | Integer | 0x0000–0xffff,0x0000000000000000–0xffffffffffffffff | Address of neighbor device connected by the link, the addressing mode may be either short or extended. A short address of 0xffff indicates the link may be used for frames destined for the broadcast address. |

MLME-SET-LINK.request primitive may be used by the device management layer to add, delete, or modify a link in a slotframe.

When Operation is set to ADD\_LINK, the MAC layer shall attempt to add the link to a new *macLinkTable* associated with the indicated slotframe. When Operation is set to DELETE\_LINK, all parameters except LinkHandle and SlotframeHandle shall be ignored, and the indicated link shall be deleted from the associated *macLinkTable*. When Operation is set to MODIFY\_LINK, the MAC layer shall attempt to update the indicated link. If the link is currently in use, the delete or modify operation shall be postponed until the link operation completes, either through a successful unacknowledged transmission, time-out for receipt of an expected acknowledgment, receipt of an invalid or unacknowledged frame, or transmission of an acknowledgment upon receipt of a valid frame. Upon completion, the result of the operation shall be reported through the corresponding MLME-SET-LINK.confirm primitive.

If LinkOptions’ b0 ~~is TRUE~~ and b2 are set to 1 ~~SharedLink is TRUE~~, ~~then~~ the device shall back off according to the method described in 6.2.5.3 ~~6.6~~. ~~If TimekeepingLink is TRUE and RxLink is TRUE then a neighbor is to be used for timing synchronization.~~ Setting LinkOptions’ b3 in addition to b1 indicates that the neighbor at NodeAddr is to be used for synchronization. LinkOptions’ shared behavior is not defined for receive links. The Timekeeping bit in the linkOptions is not defined for transmit links.

If LinkType is set to ADVERTISE, the link~~s~~ may be used to send Enhanced Beacon frames as the result of the MAC receiving a MLME-BEACON.request.

**8.4.2.2.2 TSCH MAC PIB attributes for *macLinkTable***

The attributes contained in the MAC PIB for *macLinkTable* are presented in Table 137. Each link requires a *macLinkTable* to be stored.

**Table 137—TSCH MAC PIB attributes for *macLinkTable***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** | **Default** |
| macLinkHandle | Integer | 0x0000–0xffff | Identifier of Link | — |
| *macLinkType* | ~~Enumeration~~Bitmap | ~~TX, RX, SHARED, RX\_SHARED~~0x00–0xff | Indicates how the Link ~~type~~ is used.b0 = Transmit, b1 = Receive, b2 = Shared, b3= Timekeeping, b4 = Priority, b5–b7 reserved. | — |
| *~~macLinkTimekeeping~~* | ~~Boolean~~ | ~~TRUE, FALSE~~ | ~~Set to TRUE if the link is a timekeeping link, FALSE otherwise.~~ |  |
| *macLinkType* | Enumeration | NORMAL, ADVERTISING | Type of link. | Normal |
| *macSlotframeHandle* | Integer | 0x00–0xff | Identifier of Slotframe to which this link belongs | — |
| *macNodeAddress* | Integer | 0x0000–0xfffd,0x0000000000000000–0xffffffffffffffff | ~~Short~~ address of the node connected to this link, the addressing mode may be either short or extended.  | — |
| *macTimeslot* | Integer | 0x0000–0xffff | Timeslot for this link | — |
| *macChannelOffset* | Integer | 0x0000–0xffff | Channel offset for this link | — |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bit Map dependencies | TxLink | RxLink | SharedLink | TimekeepingLink | PriorityLink |
| TxLink | — | Only if SharedLink is set | TX must backoff as per 6.2.5.3 | Not Defined |  |
| RxLink | Only if Shared-Link is set | — | Not Defined | Required if RxLink only |  |
| SharedLink | TX must backoff as per 6.2.5.3 | Not Defined | — | Not Defined |  |
| TimekeepingLink | Not Defined | Required if RxLink only | Not Defined | — |  |
| PriorityLink |  |  |  |  | — |
| Reserved |  |  |  |  |  |

TxLink=1, RxLink=0, SharedLink=0, TimekeepingLink=0, PriorityLink=Don’t Care

TxLink=1, RxLink=0, SharedLink=1, TimekeepingLink=0, PriorityLink=0

TxLink=1, RxLink=0, SharedLink=1, TimekeepingLink=0, PriorityLink=1

TxLink=1, RxLink=1, SharedLink=1, TimekeepingLink=0, PriorityLink=0

TxLink=1, RxLink=1, SharedLink=1, TimekeepingLink=0, PriorityLink=1

TxLink=0, RxLink=1, SharedLink=0, TimekeepingLink=1, PriorityLink=Don’t Care