                     6TiSCH Operation Sublayer (6top)
                    draft-wang-6tisch-6top-sublayer-01

Abstract

   The recently published [IEEE802154e] standard formalizes the concept
   of link-layer resources in LLNs. Nodes are synchronized and follow a
   schedule. A cell in that schedule corresponds to an atomic link-
   layer resource, and can be allocated to any pair of neighbors in the
   network. This allows the schedule to be built to tightly match each
   node's bandwidth, latency and energy constraints. The [IEEE802154e]
   standard does not, however, present a mechanism to do so, as building
   and managing the schedule is out of scope of the standard. This
   document describes the 6TiSCH Operation Sublayer (6top) and the
   commands it provides to upper network layers such as RPL or GMPLS.
   The set of functionalities includes feedback metrics from cell states
   so network layers can take routing decisions, TSCH configuration and
   control procedures, and the support for decentralized, centralized or
   hybrid scheduling. In addition, 6top can be configured to enable
   packet switching at layer 2.5, analogous to GMPLS.

Requirements Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and
   "OPTIONAL" in this document are to be interpreted as described in RFC
   2119 [RFC2119].

Status of This Memo

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1. Introduction

   As presented in [I-D.ietf-6tisch-tsch], the [IEEE802154e] standard
   defines the mechanisms for a TSCH node to communicate, given a
   schedule. It does not, however, define the mechanism to build and
   maintain the TSCH schedule, match that schedule to the multi-hop
   paths maintained by a network layer such as RPL or a 2.5 layer such
   as GMPLS, adapt the resources allocated between neighbor nodes to the
   data traffic flows, enforce a differentiated treatment for data
   generated at the application layer and signalling messages needed by
   6LoWPAN and RPL to discover neighbors, react to topology changes,
   self-configure IP addresses, or manage keying material.

   In a TSCH network, the MAC layer is not in charge of setting up the
   schedule that controls the connectivity graph of the network and the
   resources allocated to each node in that topology. This
   responsibility is left to the next-higher layer, defined in this
   document, called "6top".

   This document describes the 6TiSCH Operation Sublayer (6top) and the
   main commands provided to upper network layers such as RPL or GMPLS.
   The set of functionalities include feedback metrics from cell state
   so the network layer can take routing decisions, TSCH configuration
   and control procedures, and support for the different scheduling
   mechanisms defined in [I-D.ietf-6tisch-architecture]. 6top addresses
   the set of functionalities described in [I-D.ietf-6tisch-tsch].

   For example, network formation in a TSCH network involves the
   transmission of Enhanced Beacons (EB). EBs include information for
   joining nodes to be able to synchronize and set up an initial network
   topology. However, [IEEE802154e] does not specify how the period of
   EBs is configured, nor the rules for a node to select a particular
   node to join. 6top offers a set of commands so control mechanisms can
   be introduced on top of TSCH to configure nodes to join a specific
   node. Once a network is formed, 6top maintains the network's health,
   allowing for nodes to stay synchronized. It supplies mechanisms to
   manage each node's time source neighbor and configure the EB
   interval. Network layers running on top of 6top take advantage of

the TSCH MAC layer information so routing metrics, topological
information, energy consumption and latency requirements can be
adjusted to TSCH, and adapted to application requirements.

TSCH requires a mechanism to manage its schedule; 6top provides a set
of commands for upper layers to set up specific schedules, either
explicitly by detailing specific cell information, or by allowing
6top to establish a schedule given a bandwidth or latency
requirement. 6top is designed to enable decentralized, centralized or
hybrid scheduling solutions. 6top enables internal TSCH queuing
configuration, size of buffers, packet priorities, transmission
failure behavior, and defines mechanisms to encrypt and authenticate
MAC slotframes.

As described in [label-switching-154e], due to the slotted nature of
a TSCH network, it is possible to use a label switched architecture
on top of TSCH cells. As a cell belongs to a specific track, a label
header is not needed at each packet; the input cell (or bundle) and
the output cell (or bundle) uniquely identify the data flow. The
6top sublayer provides operations to manage the cell mappings.

2. 6TiSCH Operation Sublayer (6top) Overview

6top is a sublayer which is the next-higher layer for TSCH
(Figure 1), which architecture is detailed in
[I-D.ietf-6tisch-architecture], and generaic data model is detailed
in [I-D.ietf-6tisch-6top-interface]. 6top offers both management and
data interfaces to an upper layer. It includes monitoring and
statistics collection, both of which are configurable through the
management interface.

Protocol Stack

```
   +-----------------------------------+
   | PCEP | CoAP |        | 6LoWPAN |      |
   | PCC  | DTLS | PANA |     ND    |RPL |
   +--------------------------------------------+
   | TCP  |      UDP     |      ICMP    | RSVP |
   +--------------------------------------------+
   |                    IPv6                    |
   +--------------------------------------------+
   |                 6LoWPAN HC                 |
   +--------------------------------------------+
   |                   6top                     |
   +--------------------------------------------+
   |              IEEE802.15.4e TSCH            |
   +--------------------------------------------+
   |                 IEEE802.15.4              |
   +--------------------------------------------+
```
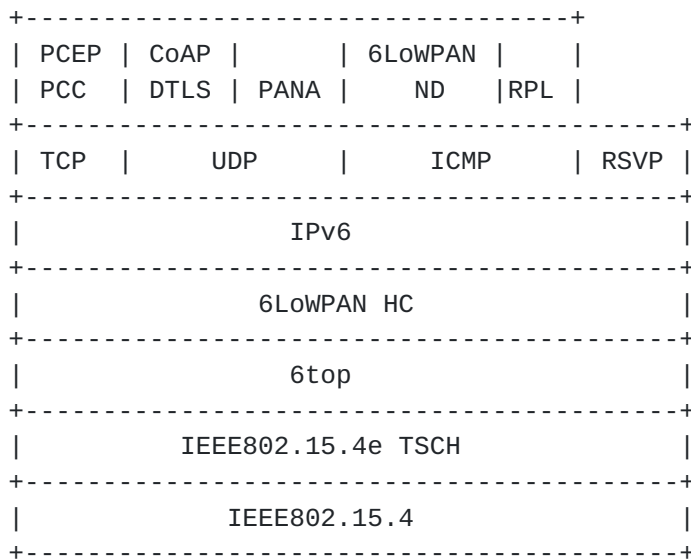
Figure 1

6top distinguishes between hard cells and soft cells. It therefore
requires an extra flag to all cells in the TSCH schedule, as detailed
in Section 2.1.

When a higher layer gives 6top a 6LoWPAN packet for transmission,
6top maps it to the appropriate outgoing priority-based queue, as
detailed in Section 2.2.

All 6top commands of the management and data interfaces are detailed
in Section 3. This set of commands is designed to support
decentralized, centralized and hybrid scheduling solutions. They
form a conceptual interface an upper layer can use; implementations
can use this set of commands, or any equivalent alternative.

6top defines TSCH Information Elements (IEs) for neighbors nodes to
negotiate scheduling cells in the TSCH schedule. The format of those
IEs is given in Section 4.1. Example data exchanges between neighbor
nodes are given in Section 4.2.

Section 5 defines how 6top gathers statistics (e.g. link quality,
energy level, queue usage), and what commands an upper layer can use
to configure and retrieve those statistics.

6top can be configured to monitor the cells it has scheduled in order
to detect cells with poor performance. It can automatically re-
allocate those cells inside the TSCH schedule. This behavior is
described in Section 6

2.1. Cell Model

   [IEEE802154e] defines a set of options attached to each cell. A cell
   can be a Transmit cell, a Receive cell, a Shared cell or a
   Timekeeping cell. These options are not exclusive, as a cell can be
   qualified with more than one of them. The MLME-SET-LINK.request
   command defined in [IEEE802154e] uses a linkOptions bitmap to specify
   the options of a cell. Acceptable values are:

         b0 = Transmit

         b1 = Receive

         b2 = Shared

         b3 = Timekeeping

         b4-b7 = Reserved

   Only Transmit cells can also be marked as Shared cells. When the
   shared bit is set, a back-off procedure is applied to handle
   collisions. Shared behavior does not apply to Receive cells.

   6top allows an upper layer to schedule a cell at a specific
   slotOffset and channelOffset, in a specific slotframe.

   In addition, 6top allows an upper layer to schedule a certain amount
   of bandwidth to a neighbor, without having to specify the exact
   slotOffset and channelOffset of the corresponding cell(s). Once
   bandwidth is reserved, 6top is in charge of ensuring that this
   requirement is continuously satisfied. 6top dynamically reallocates
   cells if needed, and over-provisions if required.

   6top allows an upper layer to associate a cell with a specific track
   by using a TrackID. A TrackID is a tuple
   (TrackOwnerAddr,InstanceID). TrackOwnerAddr is the address of the
   node which initiates the process of creating the track, i.e. the
   owner of the track. InstanceID is an instance identifier given by
   the owner of the track. InstanceID comes from the upper layer; it
   could for example be the local instance ID defined in RPL.

   If the TrackID is set to (0,0), the cell can be used by the best-
   effort QoS configuration or as a Shared cell. If the TrackID is not
   set to (0,0), i.e. the cell belongs to a specific track, the cell
   MUST not be set as Shared cell.

   6top allows an upper layer to ask a node to manage a portion of a
   slotframe, called a chunk. Chunks can be delegated explicitly by the

PCE to a node, or claimed automatically by any node that participates
to the distributed cell scheduling process. The cells in a chunk can
be appropriated by the node, i.e. the node is in charge of managing
the chunk.

Given this mechanism, 6top defines hard cells (which have been
requested specifically) and soft cells (which can be reallocated
dynamically). The hard/soft flag is introduced by the 6top sublayer
named as CellType (0: soft cell, 1: hard cell). This option is
mandatory; all cells are either hard or soft.

2.1.1. hard cells

A hard cell is a cell that cannot be dynamically reallocated by 6top.
A hard cell is uniquely identified by the following tuple:

    slotframe ID: ID of the slotframe this cell is part of.

    slotOffset: the slotOffset for the cell.

    channelOffset: the channelOffset for the cell.

    LinkOption bitmap: bitmap as defined in [IEEE802154].

    CellType: MUST be set to 1.

2.1.2. soft cells

A soft cell is a cell that can be reallocated by 6top dynamically.
The CellType MUST be set to 0. This cell is installed by 6top given
a specific bandwidth requirement. Soft cells are installed through
the soft cell negotiation procedure described in Section 4.2.

2.2. Data Transfer Model

The TSCH MAC layer is decoupled from the upper layer; the interaction
between the upper layer and TSCH is asynchronous. This means that
the MAC layer executes a schedule and checks at each timeslot
according to the type of cell(i.e Transmit, Shared or Receive),
whether there is something to send or receive. If that is the case,
the packet is transmitted and the MAC layer continues its operation.
When an upper layer sends a packet, this packet is pushed into a
queue waiting for the MAC layer to read it and send it in a
particular timeslot according to its destination and priority. 6top
provides a set of queue management operations which enable upper
layers to create different queues and set their priorities. This
allows different classes of traffic to be handled by the forwarding

plane by inserting a packet into the queue appropriate for its
priority.

A 6top implementation MUST provide at least a Broadcast Queue and a
Transmit Queue. The Broadcast Queue is associated with cells with
LinkType=ADVERTISING in the sender's schedule, and
LinkOption="Receive" and "Timekeeping" in all its neighbors'
schedule. For example, NodeA uses slotOffset=5 and channelOffset=12
as Broadcast cell to its neighbors NodeB and NodeC. Then, in the
schedule of NodeA the cell will be featured with neighbor address is
Broadcast address, LinkType=ADVERTISING; and in the schedules of both
nodeB and nodeC the cell will be featured with nodeA address as
neighbor address, and LinkOption="Receive" and "Timekeeping", which
ensure nodeB and nodeC will be active at least one time in the cell
to receive broadcast packet during a Timekeeping period. A Transmit
Queue is associated with the dedicated Transmit cells or Shared
Cells.

Data Communication Commands ([Section 3.12](#)) can be used to send
control messages and data messages. The operation is used to insert
a message into a specific queue.

For example, a configuration can include two Broadcast Queues with
priority High and Low, and three Transmit Queues with priority High,
Mid, and Low.

When DestAddr is the broadcast address, its related MAC layer packets
will be pushed into the Broadcast Queue with the corresponding
priority. 6top is responsible for feeding these packets into
broadcast cells.

When DestAddr is a unicast address, its related MAC layer packets
will be pushed into the Transmit Queue with the corresponding
priority. 6top is responsible for feeding these packets into Transmit
or Shared Cells.

The QoS policy enforced by 6top is out of scope. As an example,
packets in higher priority queues could be transmitted before the
packets in lower priority queue. As a result, when there is an
available broadcast/unicast cell, 6top checks the broadcast/unicast
queue with higher priority first. 6top continues this search until it
finds a broadcast/unicast packet, or finds that all of broadcast/
unicast queues are empty.

Figure 2 shows how 6top shapes data from the upper layer (e.g., RPL,
6LoWPAN), and feeds it to TSCH. The properties associated with a
packet/fragment from the upper layer includes the next hop neighbor
(DestAddr), the packet priority, and TrackID(s).

6top Data Transfer Model

```
                          |
                          | (DestAddr, Priority, Fragment)
                          |
      +---------------------------------------+
      |                 I-MUX                  |
      +---------------------------------------+
        |       |       |       |         |
        |       |       |       |         |
      +---+   +---+   +---+   +---+     +---+
      |   |   |   |   |   |   |   |     |   |
      |Q1 |   |Q2 |   |Q3 |   |Q4 | ... |Qn |
      |   |   |   |   |   |   |   |     |   |
      +---+   +---+   +---+   +---+     +---+
        |       |       |       |         |
        |       |       |       |         |
      +---------------------------------------+
      |                  MUX                   |
      +---------------------------------------+
                       |
                       |
                     +---+
                     |PDU|
                     +---+
                       |
                       | TSCH MAC-payload
                       |
```
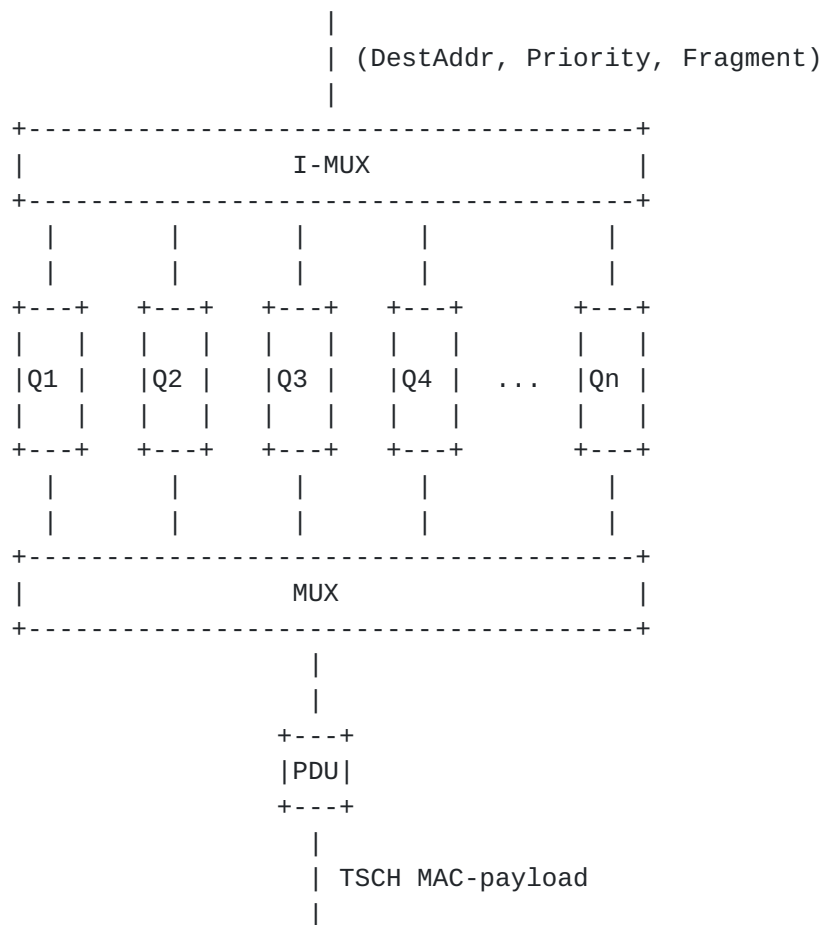
                          Figure 2

   In Figure 2, Qi represents a queue, which is either broadcast or
   unicast, and is assigned a priority. The number of queues is
   configurable. The relationship between queues and tracks is
   configurable. For example, for a given queue, only one specific
   track can be used, all of the tracks can be used, or a subset of the
   tracks can be used.

   When 6top receives a packet to transmit through a Send.data command
   (Section 3.12), the I-MUX module selects a queue in which to insert
   it. If the packet's destination address is a unicast (resp.
   broadcast) address, it is inserted into a unicast (resp. broadcast)
   queue.

   The MUX module is invoked at each scheduled transmit cell by TSCH.
   When invoked, the MUX module goes through the queues, looking for the
   best matching frame to send. If it finds a frame, it hands it over

to TSCH for transmission. If the next active cell is a broadcast
cell, it selects a fragment only from broadcast queues.

How the MUX module selects the best frame is configurable. The
following rules are a typical example:

> The frame's layer 2 destination address MUST match the neighbor
> address associated with the transmit cell.
>
> If the transmit cell is associated with a specific track, the
> frames in the queue corresponding to the TrackID have the
> highest priority.
>
> If the transmit cell is not associated with a specific track,
> i.e., TrackID=(0,0), frames from a queue with a higher priority
> MUST be sent before frames from a queue with a lower priority.

Further rules can be configured to satisfy specific QoS requirements.

3. 6top Commands

6top provides a set of commands as the interface with the higher
layer. Most of these commands are related to the configuration of
slotframes, cells and scheduling information. 6top also provides an
interface allowing an upper layer to retrieve status information and
statistics. The management commands provided by 6top are listed
below. Note that this set defines a conceptual interface only; an
implementation can choose to use this exact set of commands, or any
equivalent alternative.

> CREATE.hardcell: Section 3.1.1
>
> CREATE.softcell: Section 3.1.2
>
> READ.cell: Section 3.1.3
>
> UPDATE.cell: Section 3.1.4
>
> DELETE.hardcell: Section 3.1.5
>
> DELETE.softcell: Section 3.1.6
>
> REALLOCATE.softcell: Section 3.1.7
>
> CREATE.slotframe: Section 3.2.1
>
> READ.slotframe: Section 3.2.2

READ.chunk: [Section 3.10.2](#)

DELETE.chunk: [Section 3.10.3](#)

CREATE.hardcell.fromchunk: [Section 3.11.1](#)

READ.chunkcell: [Section 3.11.2](#)

DELETE.hardcell.fromchunk: [Section 3.11.3](#)

Besides management commands, 6top provides the following data commands:

Send.data: [Section 3.12.1](#)

Receive.data: [Section 3.12.2](#)

In addition, 6top offers a delegation interface allowing an upper layer to configure TSCH. 6top only delegates the functionalities to the MAC security services. In other words, 6top allows an upper layer to access the security PIB (Table 60, Table 61, Table 63 in [[IEEE802154](#)]) by using MLME-GET/MLME-SET primitives defined in [[IEEE802154](#)].

[3.1](#). Cell Commands

6top provides the following commands to manage TSCH cells.

[3.1.1](#). CREATE.hardcell

Creates one or more hard cells in the schedule. Fails if the cell already exists. A cell is uniquely identified by the tuple (slotframe ID, slotOffset, channelOffset).

To create a hard cell, the upper layer specifies:

slotframe ID: ID of the slotframe this timeslot will be scheduled in.

slotOffset: the slotOffset for the cell.

channelOffset: channelOffset for the cell.

LinkOption bitmap: bitmap as defined in [[IEEE802154e](#)]

LinkType : as defined in section 6.2.19.3 of [[IEEE802154e](#)].

CellType: as defined in [Section 2.1](#)

target node address: the address of that node to communicate
with over this cell. In case of broadcast cells this is the
broadcast address.

TrackID: ID of the track the cell will belong to.

6top schedules the cell and marks it as a hard cell, indicating that
it cannot reschedule this cell. The return value is CellID and the
created cell is also filled in CellList
([I-D.ietf-6tisch-6top-interface]).

The interaction between 6top and MAC layer caused by CREATE.hardcell
is as follows.

Firstly, 6top calls the primitive MLME-SET-LINK.request defined in
section 6.2.19.3 of [IEEE802154e]. The primitive parameters are set
as follows.

```
+-------------------------------+-------------------------------+
| MLME-SET-LINK.request parameter |          set by 6top        |
+-------------------------------+-------------------------------+
|    operation                  |  ADD-LINK                     |
+-------------------------------+-------------------------------+
|    LinkHandle                 |  CellID                       |
+-------------------------------+-------------------------------+
|    slotframeHandle            |  slotframe ID                 |
+-------------------------------+-------------------------------+
|    timeslot                   |  slotOffset                   |
+-------------------------------+-------------------------------+
|    channelOffset              |  channelOffset                |
+-------------------------------+-------------------------------+
|    LinkOptions                |  LinkOption bitmap            |
+-------------------------------+-------------------------------+
|    LinkType                   |  LinkType                     |
+-------------------------------+-------------------------------+
|    nodeAddr                   |  target node address          |
+-------------------------------+-------------------------------+
```

Secondly, if the status from MLME-SET-LINK.confirm defined in section
6.2.19.4 of [IEEE802154e] is SUCCESS, then add the LinkHandle to the
BundleList specified by TrackID, and confirm to upper layer with
status = SUCCESS; otherwise, confirm to upper layer with status =
FAIL.

3.1.2. CREATE.softcell

To create soft cell(s), the upper layer specifies:

> slotframe ID: ID of the slotframe the cell(s) will be scheduled
> in
>
> number of cells: the required number of soft cells.
>
> LinkOption bitmap: bitmap as defined in [IEEE802154e]
>
> CellType: as defined in Section 2.1
>
> target node address: the address of the node to communicate
> with over the cell(s). In case of broadcast cells this is the
> broadcast address.
>
> TrackID: ID of the track the cell(s) will belong to.
>
> QoS level: the cell redundancy policy. The policy can be for
> example STRICT, BEST_EFFORT, etc.

6top is responsible for picking the exact slotOffset and
channelOffset in the schedule, and ensure that the target node choose
the same cell and TrackID. 6top marks these cells as soft cell,
indicating that it will continuously monitor their performance and
reschedule if needed. The return value is CellID, and the created
cell is also filled in CellList ([I-D.ietf-6tisch-6top-interface]).

6top deals with the allocation process by negotiation with the target
node. The command returns the number and the list of created cells
defined by (slotframe ID, slotOffset, channelOffset). The number of
crated cells is less than the required number of cells if the
required number of cells is higher than the available number of cells
in the schedule. The number of created cells equals to zero if the
negotiation with the target node fails. The number of created cells
equals to zero if the CellType bitmap indicates that the cell(s) MUST
be Hard.

The interaction between 6top and TSCH happens on both sides described
as follows.

For example, after negotiation, node A and node B find a specific
cell, slotOffset=10, channelOffset=12, as a Tx cell and Rx cell,
respectively, then the 6top in node A and node B will call the
primitive MLME-SET-LINK.request defined in section 6.2.19.3 of
[IEEE802154e], respectively. The primitive parameters are set in
node A and node B as follows.

```
+--------------------------------+--------------------------------+
| MLME-SET-LINK.request parameter | set by A's 6top | set by B's top|
+--------------------------------+--------------------------------+
|    operation                   | ADD-LINK     | ADD-LINK      |
+--------------------------------+--------------------------------+
|    LinkHandle                  | CellID       | CellID        |
+--------------------------------+--------------------------------+
|    slotframeHandle             | slotframe ID | slotframe ID  |
+--------------------------------+--------------------------------+
|    timeslot                    | 10           | 10            |
+--------------------------------+--------------------------------+
|    channelOffset               | 12           | 12            |
+--------------------------------+--------------------------------+
|    LinkOptions                 | Tx           | Rx            |
+--------------------------------+--------------------------------+
|    LinkType                    | NORMAL       | NORMAL        |
+--------------------------------+--------------------------------+
|    nodeAddr                    | Node A       | Node B        |
+--------------------------------+--------------------------------+
```

If the Status from MLME-SET-LINK.confirm defined in section 6.2.19.4
of [IEEE802154e], 6top will notify upper layer failure.

3.1.3. READ.cell

Given a (slotframe ID, slotOffset, channelOffset), retrieves the cell
information. Fails if the cell does not exist. The returned
information contains:

> slotframe ID: ID of the slotframe where this cell is installed.

> slotOffset: the slotOffset for the cell.

> channelOffset: the selected channelOffset for the cell.

> LinkOption bitmap: bitmap as defined in [IEEE802154e]

> CellType: as defined in Section 2.1

> target node address: the target address of that cell. In case
> of broadcast cells this is the broadcast address.

> TrackID: ID of the track the cell will belong to.

> NumOfStatistics: Number of elements in the following list of
> tuple (StatisticsMetriceID and StatisticsValue)

list of (StatisticsMetriceID, StatisticsValue):
StatisticsMetriceID is the index to Statistics Metric defined
in [Section 3.4](#), StatisticsValue is the value corresponding to
the metric indexed by StatisticsMetriceID

A read command can be issued for any cell, hard or soft. 6top gets
cell information from CellList ([I-D.ietf-6tisch-6top-interface]).

3.1.4. UPDATE.cell

Update a hard cell, i.e., re-allocate it to a different slotOffset
and/or channelOffset. Fails if the cell does not exist. Requires
both old (slotframe ID, slotOffset, channelOffset) and new (slotframe
ID, slotOffset, channelOffset) as parameters. And, the type of cell,
target node address and TrackID are the fields that cannot be
updated. Soft cells MUST NOT be updated by the UPDATE.cell command.
REALLOCATE.softcell ([Section 3.1.7](#)) MUST be used instead.

It causes a old cell being removed and a new cell being created.

3.1.5. DELETE.hardcell

To remove a hard cell, the upper layer specifies:

slotframe ID: the ID of the slotframe where this cell is
installed.

slotOffset: the slotOffset for the cell.

channelOffset: the selected channelOffset for the cell.

LinkOption bitmap: bitmap as defined in [IEEE802154e]

LinkType : as defined in section 6.2.19.3 of [IEEE802154e].

CellType: as defined in [Section 2.1](#)

target node address: the target address of that cell. In case
of broadcast cells this is the broadcast address.

TrackID: ID of the track the cell will belong to.

This removes the hard cell from the node's schedule, from CellList
([I-D.ietf-6tisch-6top-interface])as well.

The interaction between 6top and MAC layer caused by DELETE.hardcell
is as follows.

Firstly, 6top calls the primitive MLME-SET-LINK.request defined in
section 6.2.19.3 of [IEEE802154e]. The primitive parameters are set
as follows.

```
+-------------------------------+-------------------------------+
| MLME-SET-LINK.request parameter |          set by 6top          |
+-------------------------------+-------------------------------+
|    operation                  |   DELETE-LINK                 |
+-------------------------------+-------------------------------+
|    LinkHandle                 |   CellID                      |
+-------------------------------+-------------------------------+
|    slotframeHandle            |   slotframe ID                |
+-------------------------------+-------------------------------+
|    timeslot                   |   slotOffset                  |
+-------------------------------+-------------------------------+
|    channelOffset              |   channelOffset               |
+-------------------------------+-------------------------------+
|    LinkOptions                |   LinkOption bitmap           |
+-------------------------------+-------------------------------+
|    LinkType                   |   LinkType                    |
+-------------------------------+-------------------------------+
|    nodeAddr                   |   target node address         |
+-------------------------------+-------------------------------+
```

Secondly, if the status from MLME-SET-LINK.confirm defined in section
6.2.19.4 of [IEEE802154e] is SUCCESS, then remove the LinkHandle from
its BundleList specified by TrackID, and confirm to upper layer with
status = SUCCESS; otherwise, confirm to upper layer with status =
FAIL.

3.1.6. DELETE.softcell

To remove a (number of) soft cell(s), the upper layer specifies:

   slotframe ID: ID of the slotframe where this cell is installed.

   number of cells: the number of cells to be removed

   LinkOption bitmap: bitmap as defined in [IEEE802154e]

   CellType: as defined in Section 2.1

   target node address: the target address of that cell. In case
   of broadcast cells this is the broadcast address.

   TrackID: ID of the track the cell will belong to.

In the case a soft cell wants to be re-allocated from the allocated cell so a hard cell can be installed instead, the REALLOCATE.softcell (Section 3.1.7) MUST be used.

After the pair of nodes figure out the specific cell(s) to be removed, the interaction between 6top and TSCH on both sides will be similar to that caused by DELETE.hardcell, except LinkType should be set to NORMAL.

3.1.7. REALLOCATE.softcell

To force a re-allocation of a soft cell, the upper layer specifies:

> slotframe ID: ID of the slotframe where the cell is allocated.

> slotOffset: the slotOffset for that cell.

> channelOffset: the channelOffset for that cell.

The reallocated cell will be installed in a different slotOffset, channelOffset but slotframe and TrackID remain the same. Hard cells MUST NOT be reallocated.

The interaction between 6top and TSCH caused by this command includes that described in Section 3.1.6 and Section 3.1.2.

3.2. Slotframe Commands

6top provides the following commands to manage TSCH slotframes.

3.2.1. CREATE.slotframe

Creates a new slotframe. The command requires:

> slotframe ID: unique identifier of the slotframe, corresponding to its priority.

> number of timeslots: the required number of timeslots in the slotframe.

Fails if the number of required timeslots is less than zero.

The interaction between 6top and MAC layer caused by CREATE.slotframe is as follows.

Firstly, 6top calls the primitive MLME-SET-SLOTFRAME.request defined in section 6.2.19.1 of [IEEE802154e]. The primitive parameters are set as follows.

```
+-------------------------------+-------------------------------+
| MLME-SET-SLOTFRAME.request    |                               |
|        parameter              |          set by 6top          |
+-------------------------------+-------------------------------+
|     slotframeHandle           |    slotframe ID               |
+-------------------------------+-------------------------------+
|     operation                 |    ADD                        |
+-------------------------------+-------------------------------+
|     size                      |    number of timeslot         |
+-------------------------------+-------------------------------+
```

Secondly, if the status from MLME-SET-SLOTFRAME.confirm defined in section 6.2.19.2 of [IEEE802154e] is SUCCESS, then confirms to upper layer with status = SUCCESS; otherwise, confirm to upper layer with status = FAIL.

3.2.2. READ.slotframe

Returns the information of a slotframe given its slotframe ID. The command returns:

> slotframe ID: ID of the slotframe. (SlotFrameHandle)

> number of timeslots: the number of timeslots in the slotframe.

Fails if the slotframe ID does not exist.

3.2.3. UPDATE.slotframe

Change the number of timeslots in a slotframe. The command requires:

> slotframe ID: ID of the slotframe.

> number of timeslots: the number of timeslots to be updated.

Fails if the number of required timeslots is less than zero. Fails if the slotframe ID does not exist.

The interaction between 6top and MAC layer caused by UPDATE.slotframe is as follows.

Firstly, 6top calls the primitive MLME-SET-SLOTFRAME.request defined in section 6.2.19.1 of [IEEE802154e]. The primitive parameters are set as follows.

```
+-------------------------------+-------------------------------+
| MLME-SET-SLOTFRAME.request    |                               |
|        parameter              |          set by 6top          |
+-------------------------------+-------------------------------+
|    slotframeHandle            |   slotframe ID                |
+-------------------------------+-------------------------------+
|    operation                  |   MODIFY                      |
+-------------------------------+-------------------------------+
|    size                       |   number of timeslot          |
+-------------------------------+-------------------------------+
```

Secondly, if the status from MLME-SET-SLOTFRAME.confirm defined in
section 6.2.19.2 of [IEEE802154e] is SUCCESS, then confirms to upper
layer with status = SUCCESS; otherwise, confirm to upper layer with
status = FAIL.

3.2.4. DELETE.slotframe

Deletes a slotframe. The command requires:

> slotframe ID: ID of the slotframe.

> number of timeslot: the number of timeslots in the slotframe.

Fails if the slotframe ID does not exist.

The interaction between 6top and MAC layer caused by DELETE.slotframe
is as follows.

Firstly, 6top calls the primitive MLME-SET-SLOTFRAME.request defined
in section 6.2.19.1 of [IEEE802154e]. The primitive parameters are
set as follows.

```
+-------------------------------+-------------------------------+
| MLME-SET-SLOTFRAME.request    |                               |
|        parameter              |          set by 6top          |
+-------------------------------+-------------------------------+
|    slotframeHandle            |   slotframe ID                |
+-------------------------------+-------------------------------+
|    operation                  |   DELETE                      |
+-------------------------------+-------------------------------+
|    size                       |   number of timeslot          |
+-------------------------------+-------------------------------+
```

Secondly, if the status from MLME-SET-SLOTFRAME.confirm defined in
section 6.2.19.2 of [IEEE802154e] is SUCCESS, then confirms to upper
layer with status = SUCCESS; otherwise, confirm to upper layer with
status = FAIL.

3.3. Monitoring Commands

   Monitoring commands provide the means for upper layers to configure
   whether 6top must ensure the required bandwidth. This procedure is
   achieved through overprovisioning according to cell status feedback.
   Monitoring is also in charge of reallocating soft cells that are
   under the required QoS.

3.3.1. CONFIGURE.monitoring

   Configures the level of QoS the Monitoring process MUST enforce. The
   command requires:

        slotframe ID: ID of the slotframe.

        target node address: the target neighbor address.

        enforce policy: The policy used to enforce the QoS
        requirements. Can be for example DISABLE, BEST_EFFORT, STRICT,
        OVER-PROVISION, etc.

   Fails if the slotframe ID does not exist.

3.3.2. READ.monitoring.status

   Reads the current Monitoring status. Requires the following
   parameters.

        slotframe ID: the ID of the slotframe.

        target node address: the target neighbor address.

   Returns the QoS levels for that Target node on that slotframe.

        allocated_hard: Number of hard cells allocated.

        allocated_soft: Number of soft cells allocated.

        provisioned: the extra provisioned cells. 0 if CONFIGURE.qos
        enforce is DISABLE.

        QoS: the current QoS. Including overprovisioned cells, i.e
        what bandwidth is being obtained including the overprovisioned
        cells.

        RQoS: the real QoS without provisioned cells. What is the
        actual bandwidth without taking into account the
        overprovisioned cells.

Fails if the slotframe ID does not exist.

3.4. Statistics Commands

6top keeps track of TSCH statistics for upper layers to adapt
correctly to medium changes. The exact metrics for statistics are
out of scope but the present commands SHOULD be used to configure and
read monitored information regardless of the specific metric.

3.4.1. CONFIGURE.statistics

Configures Statistics process. The command requires:

> slotframe ID: ID of the slotframe. If empty monitors all
> slotframe IDs

> slotOffset: specific slotOffset to be monitored. If empty all
> timeslots are monitored

> channelOffset: specific channelOffset to be monitored. If
> empty all channels are monitored.

> target node address: the target neighbor address. If empty,
> all neighbor nodes are monitored.

> metric: metric to be monitored. This MAY be PDR, ETX, queuing
> statistics, energy-related metrics, etc.)

> window: time window to be considered for the calculations. If
> 0 all historical data is considered.

> enable: Enables statistics or disables them.

Fails if the slotframe ID does not exist. The statistics service can
be configured to retrieve statistics at different levels. For
example to aggregate information by slotframe ID, or to retrieve
statistics for a particular timeslot, etc. The CONFIGURE.statistics
enables flexible configuration and supports empty parameters that
will force 6top to conduct statistics on all members of that
dimension. For example, if ChannelOffset is empty and metric is set
as PDR, then, 6top will conduct the statistics of PDR on all of
channels.

3.4.2. READ.statistics

Reads a metric for the specified dimension. Information is
aggregated according to the parameters. The command requires:

slotframe ID: ID of the slotframe. If empty aggregates
information of all slotframe IDs

slotOffset: the specific slotOffset for which the information
is required. If empty all timeslots are aggregated

channelOffset: the specific channelOffset for which the
information is required. If empty all channels are aggregated.

target node address: the target neighbor address. If empty all
neighbor addresses are aggregated.

metric: metric to be read.

Returns the value for the requested metric.

Fails if empty metric or metric does not exits.

3.4.3. RESET.statistics

Resets the gathered statistics. The command requires:

slotframe ID: ID of the slotframe. If empty resets the
information of all slotframe IDs

slotOffset: the specific slotOffset for which the information
wants to be reset. If empty statistics from all timeslots are
reset

channelOffset: the specific channelOffset for which the
information wants to be reset. If empty all statistics for all
channels are reset.

target node address: the target neighbor address. If empty all
neighbor addresses are aggregated.

metric: metric to be reset.

Fails if empty metric or metric does not exits.

3.5. Network Formation Commands

EBs need to be configured, including their transmission period, the
slotOffset and channelOffset that they SHOULD be sent on, and the
join priority they contain. The parameters for that command are
optional and enable flexible configuration of EBs. If slotframe ID
is specified, the EBs will be configured to use that specific
slotframe; if not, they will use the first slotframe where the

configured slotOffset is allocated. The slotOffset enforces the EB
to a specific timeslot. In case slotOffset parameter is not present,
the EB is sent in the first available transmit timeslot. In case
channelOffset parameter is not set, the EB is configured to use the
first available channel.

3.5.1. CONFIGURE.eb

Configures EBs. The command requires:

> slotframe ID: ID of the slotframe where the EBs MUST be sent.
> Zero if any slotframe can be used.

> slotOffset: the slotOffset where the EBs MUST be sent. Zero if
> any timeslot can be used.

> channelOffset: the channelOffset where the EBs MUST be sent.
> Zero if any channelOffset can be used.

> period: the EBs period, in seconds.

> Expiration: when the EBs periodicity will stop. If Zero the
> period never stops.

> priority: the joining priority model that will be used for
> advertisement. Joining priority MAY be for example
> SAME_AS_PARENT, RANDOM, BEST_PARENT+1 or DAGRANK(rank) as
> decribed in in [I-D.ietf-6tisch-minimal].

Fails if the tuple (slotframe ID, slotOffset, channelOffset) is
already scheduled.

3.5.2. READ.eb

Reads the EBs configuration. No parameters are required.

Returns the current EBs configuration for that slotframe, which
contains:

> slotframe ID: the slotframe where the EB is being sent.

> slotOffset: the slotOffset where the EBs is being sent.

> channelOffset: the channelOffset the EBs is being sent on.

> period: the EBs period.

Expiration: when the EBs periodicity stops. If 0 the period
never stops.

priority: the joining priority that this node advertises.

Fails if the slotframe ID does not exist.

3.6. Time Source Neighbor Commands

Commands to select time source neighbors.

3.6.1. CONFIGURE.timesource

Configures the Time Source Neighbor selection process. More than one
time source neighbor can be selected. The command requires:

selection policy: The policy used to select the time source
neighbor. The policy MAY be for example ALL_PARENTS,
BEST_CONNECTED, LOWEST_JOIN_PRIORITY, etc.

Fails if any of the time source neighbors do not exist or it is not
reachable.

3.6.2. READ.timesource

Retrieves information about the time source neighbors of that node.
The command does not require any parameter.

Returns the following information for each of the time sources:

target node: address of the time source neighbor.

statistics: includes for example minimum, maximum, average time
correction for that time source neighbor

policy: the used policy

Fails if the slotframe ID or no time source neighbors exist.

3.7. Neighbor Commands

Commands to manage neighbor table. The commands SHOULD be used by
the upper layer to query the neighbor related information and by the
lower layer to keep track of neighbors information.

[3.7.1](#). CREATE.neighbor

Creates an entry for a neighbor in the neighbor table.

>   neighbor address: The address of the neighbor.

>   neighbor stats: for example, RSSI of the last received packet
>   from that neighbor, ASN when that neighbor has been added, etc.

Returns whether the neighbor is created or not.

[3.7.2](#). READ.all.neighbor

Returns the list of neighbors of that node. Fails if empty. For
each neighbor in the list it returns:

>   neighbor address: The address of the neighbor.

>   neighbor stats: for example, RSSI of the last received packet
>   from that neighbor, ASN when that neighbor has been added,
>   packets received from that neighbor, packets sent to it, etc.

[3.7.3](#). READ.neighbor

Returns the information of a specific neighbor of that node specified
by its neighbor address. Fails if it does not exists. For that
neighbor it returns:

>   neighbor address: The address of the neighbor.

>   neighbor stats: for example, RSSI of the last received packet
>   from that neighbor, ASN when that neighbor has been added,
>   packets received from that neighbor, packets sent to it, etc.

[3.7.4](#). UPDATE.neighbor

Updates an entry for a neighbor in the neighbor table. Fails if the
neighbor does not exist. Updates stats parameters. Requires:

>   neighbor address: The address of the neighbor.

>   neighbor stats: for example, RSSI of the last received packet
>   from that neighbor, ASN when that neighbor has been added, etc.

Returns whether the neighbor is updated or not.

3.7.5. DELETE.neighbor

Deletes a neighbor given its address. Fails if the neighbor does not
exists.

3.8. Queueing Commands

Queues need to be configured. This includes queue length,
retransmission policy, discarding of packets, etc.

3.8.1. CREATE.queue

Creates and Configures Queues. The command SHOULD be applied for
each required queue. The command requires:

> txqlength: the desired transmission queue length.

> rxqlength: the desired reception queue length.

> numrtx: number of allowed retransmissions.

> age: discard packet according to its age on the queue. 0 if no
> discards are allowed.

> rtxbackoff: retransmission backoff in number of slotframes. 0
> if next available timeslot wants to be used.

> statswindow: window of time used to compute statistics.

> queue priority: the priority of this queue.

> TrackIDs: a set of TrackIDs. While it is empty, no specific
> track is associated with the queue

Returns the queue ID.

3.8.2. READ.queue

Reads the queue configuration. Requires the queue ID.

The command returns:

> txqlength: the transmission queue length.

> rxqlength: the reception queue length.

> numrtx: number of allowed retransmissions.

age: maximum age of a packet before being discarded. 0 if no
discards are allowed.

rtxbackoff: retransmission backoff in number of slotframes. 0
if next available timeslot is used.

3.8.3. READ.queue.stats

Reads the queue stats. Requires queue ID.

The command returns:

txqlengthstats: average, maximum, minimum length of the
transmission queue.

rxqlengthstats: average, maximum, minimum length of the
reception queue.

numrtxstats: average, maximum, minimum number of
retransmissions.

agestats: average, maximum, minimum age of a packet in the
queue.

rtxbackoffstats: average, maximum, minimum retransmission
backoff.

queue priority: the priority of this queue.

TrackIDs: a set of TrackIDs.

3.8.4. UPDATE.queue

Update a Queue. The command requires:

queueid: the queue ID.

txqlength: the desired transmission queue length.

rxqlength: the desired reception queue length.

numrtx: number of allowed retransmissions.

age: discard packet according to its age on the queue. 0 if no
discards are allowed.

rtxbackoff: retransmission backoff in number of slotframes. 0
if next available timeslot wants to be used.

statswindow: window of time used to compute stats.

queue priority: the desired priority of this queue.

TrackIDs: the desired set of TrackIDs.

3.8.5. DELETE.queue

Deletes a Queue. The command requires the queue ID. All packets in
the queue are discarded and the queue is deleted.

3.9. Label Switching Commands

6top is responsible for maintaining the mapping of input cells and
output cells in the same track in a particular node. By keeping that
mapping, layer 3 routing can be avoided as packets are forwarded by
the 6top sublayer according to the input cells they were received on.
The selected output cell is one of the cells that forward the packet
to the subsequent hop in the track.

3.9.1. LabelSwitching.map

The command used by an upper layer to map an input cell or a bundle
of input cells to an output cell or a bundle of output cells. 6top
stores this mapping and makes sure that the packets are forwarded at
the specific output cell/bundle. Label Switching is enabled by the
specified bundle as soon as the mapping is installed.

The required parameters are:

input cells: list of input cells (one or more cells in a
bundle). Each input cells is described by an unique tuple
(slotOffset, channelOffset, destination address).

output cells: list of output cells (one or more cells in a
bundle). Each output cells is described by an unique tuple
(slotOffset, channelOffset, destination address).

load balancing policy: A policy for load balance cell usage.
The policy is out of scope, however an example can be use ROUND
ROBIN policy within the cells of the same bundle.

3.9.2. LabelSwitching.unmap

The command used by upper layers to unmap one input cell or a bundle
of input cells to an output cell or a bundle of output cells. The
mapping is removed from the state kept by 6top.

The required parameters are:

>   input cells: list of input cells (one or more cells in a
>   bundle). Each input cells is described by an unique tuple
>   (slotOffset, channelOffset, destination address).

>   output cells: list of output cells (one or more cells in a
>   bundle). Each output cells is described by an unique tuple
>   (slotOffset, channelOffset, destination address).

3.10. Chunk Command

3.10.1. Create.chunk

Create a chunk which consists of one or more unappropriated cells.

To create a chunk, upper layer specifies:

>   slotframe ID: ID of the slotframe which this chunk belongs to.

>   ChunkSize: number of the cells which the chunk includes.

>   SlotBase : the base slotOffset of the chunk.

>   SlotStep : the incremental of slotOffset in the chunk.

>   ChannelBase: the base channelOffset of the chunk.

>   ChannelStep: the incremental of channalOffset in the chunk.

ChunkID is the return value of the command
([I-D.ietf-6tisch-6top-interface]). The chunk is a set of cells in
the given slotframe, consisting of (slotOffset(i),channelOffset(i)),
i=0..Chunksize-1, slotOffset(i)= (slotBase + i * slotStep) %
slotframeLen, channelOffset(i) = (channelBase + i * channelStep) %
16". Those cells will be added into ChunkCellList
([I-D.ietf-6tisch-6top-interface]) also.

3.10.2. READ.chunk

Returns the information of a chunk given its ChunkId. The command
returns:

>   slotframe ID: ID of the slotframe which this chunk belongs to.

>   ChunkSize: number of the cells which the chunk includes.

>   SlotBase : the base slotOffset of the chunk.

SlotStep : the incremental of slotOffset in the chunk.

ChannelBase: the base channelOffset of the chunk.

ChannelStep: the incremental of channalOffset in the chunk.

Fails if the ChunkId does not exist.

3.10.3. Delete.chunk

To delete a chunk, upper layer specifies ChunkID.

It removes the chunk from ChunkList
([I-D.ietf-6tisch-6top-interface]), and also remove those entries
corresponding to the cells of the chunk from
ChunkCellList([I-D.ietf-6tisch-6top-interface]). In addition, it
also causes all of the scheduled cells in the chunk are deleted from
CellList ([I-D.ietf-6tisch-6top-interface]) and TSCH schedule as
well.

3.11. Chunk Cell Command

3.11.1. CREATE.hardcell.fromchunk

Creates one or more hard cells from a chunk. Fails if the cell
already exists. A cell is uniquely identified by the tuple
(slotframe ID, slotOffset, channelOffset).

To create a hard cell from a chunk which is corresponding to a
specific slotframe ID, the upper layer specifies:

chunkID: ID of the chunk which this cell belongs to.

slotOffset: the slotOffset for the cell.

channelOffset: channelOffset for the cell.

LinkOption bitmap: bitmap as defined in [IEEE802154e]

LinkType : as defined in section 6.2.19.3 of [IEEE802154e].

CellType: as defined in Section 2.1

target node address: the address of that node to communicate
with over this cell. In case of broadcast cells this is the
broadcast address.

TrackID: ID of the track the cell will belong to.

6top schedules the cell and marks it as a hard cell, indicating that it cannot reschedule this cell. In addition, 6top will change the attributes corresponding to the cell in the ChunkCellList, i.e. its CellID is changed to the same CellID in the CellList, and its Status is changed to USED ([I-D.ietf-6tisch-6top-interface]).

The interaction between 6top and MAC layer caused by CREATE.hardcell.fromchunk is same as that caused by CREATE.hardcell (Section 3.1.1).

3.11.2. READ.chunkcell

Returns the cell information of a chunk given its ChunkId. For each cell of the chunk, the command returns:

> slotOffset: the slotOffset of the cell.

> channelOffset: channelOffset of the cell.

> cellId: the cellID in the CellList if scheduled.

> Status: USED/UNUSED

Fails if the ChunkId does not exist.

3.11.3. DELETE.hardcell.fromchunk

To remove a hard cell which comes from a chunk, the upper layer specifies:

> slotframe ID: the ID of the slotframe where this cell is installed.

> slotOffset: the slotOffset for the cell.

> channelOffset: the selected channelOffset for the cell.

> LinkOption bitmap: bitmap as defined in [IEEE802154e]

> LinkType : as defined in in section 6.2.19.3 of [IEEE802154e].

> CellType: as defined in Section 2.1

> target node address: the target address of that cell. In case of broadcast cells this is the broadcast address.

> TrackID: ID of the track the cell will belong to.

This removes the hard cell from the node's schedule and CellList
([I-D.ietf-6tisch-6top-interface]). In addition, it changes the
attributes corresponding to the cell in the ChunkCellList, i.e. its
CellID is changed back to FFFF, and its Status is changed to UNUSED
([I-D.ietf-6tisch-6top-interface]).

The interaction between 6top and MAC layer caused by DELETE.hardcell
is same as that caused by DELETE.hardcell (Section 3.1.5).

3.12. Data Commands

3.12.1. Send.data

The command used by upper layers to queue a packet so underlying TSCH
sends it. According to the specific priority, the packet is pushed
into a Queue with the equivalent priority or following a criteria out
of scope. Once a packet is inserted into a queue it waits to be
transmitted by TSCH according to the model defined in Section 2.2.
If the queue is full or destination address is not a L2 neighbor of
the node, failure to enqueue will be indicated to the caller.

The required parameters are:

> src address: L2 address

> dest address: L2 unicast or broadcast address

> priority: packet priority, usually is consistent with queue
> priority

> message length: the length of the message

> message: control message or data message

> securityLevel:As defined by [IEEE802154e].

3.12.2. Receive.data

The command is invoked whenever a packet is received and inserted
into a reception queue. The method acts as a callback function to
notify to the upper layers the received message. Upper layers MUST
terminate this indication.

The function has the following parameters:

> src address: L2 source address

> dest address: L2 unicast or broadcast destination address

   priority: packet priority, usually is consistent with queue
   priority

   message length: the length of the message.

   message: control message or data message

4. 6top Communication Protocol

   This section defines the Information Element (IE) based message
   formats, and the 6top-to-6top communication time sequences.

4.1. Message Formats

   6top has to negotiate the scheduling of soft cells with neighbor
   nodes. This negotiation happens through 6top-specific TSCH
   Information Elements, the format of which is defined in this section.
   For completeness, this section also details the formats of the IEs
   already defined in [IEEE802154e] and presented here without
   modification.

   6top messages can contain one or more IEs. Section 4.1.1 defines the
   different IEs used by 6top, both the ones used without modification
   from [IEEE802154e], and the new ones defined by this document.
   Section 4.1.2 shows how several IEs are assembled to form the
   different frames used by 6top.

4.1.1. Information Elements

   [IEEE802154e] defines Information elements (IEs). IEs are formatted
   data objects consisting of an ID, a length, and a data payload used
   to pass data between layers or devices. [IEEE802154e] defines Header
   IEs and Payload IEs; 6top only uses Payload IEs. A Payload IE
   includes one or more IEs, and ends with a termination IE (ID = 0x0f,
   see [IEEE802154e]).

   6top uses the following Information Elements, some defined in
   [IEEE802154e], others introduced in this document.

      Defined in [IEEE802154e] and used by 6top without modification:

         TSCH Synchronization IE (Section 4.1.1.1)

         TSCH Slotframe and Link IE (Section 4.1.1.2)

         TSCH Timeslot Template IE (Section 4.1.1.3)

TSCH Channel Hopping IE (Section 4.1.1.4)

Defined by 6top:

6top Opcode IE (Section 4.1.1.5)

6top Bandwidth IE (Section 4.1.1.6)

6top TrackID IE (Section 4.1.1.7)

6top Generic Schedule IE (Section 4.1.1.8)

4.1.1.1. TSCH Synchronization IE

A Synchronization IE (SyncIE) contains Information allowing a node to synchronize to a TSCH network, including the current ASN and a join priority. Synchronization IE MUST be included in all TSCH Enhanced Beacons.

6top re-uses this IE as defined in [IEEE802154e].

Format of a TSCH Synchronization IE (SyncIE).

```
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |    Length     |    SubID    |T|            ASN               |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                  ASN                    | Join Priority |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
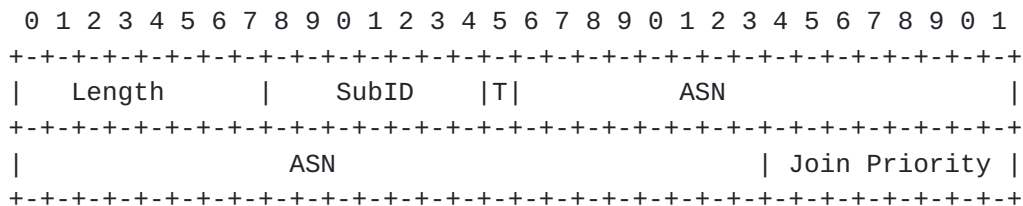
Figure 3

Length=6

SubID=0x1a

T=0, i.e., short type

ASN (5 octets) contains the Absolute Slot Number corresponding to the timeslot in which the TSCH Enhanced Beacon is sent.

The Join Priority can be used by a joining device to select among beaconing devices when multiple beacons are heard. The PAN coordinator's join priority is zero. A lower value of join priority indicates that the device is the preferred one to connect to. As

suggested by [I-D.ietf-6tisch-minimal], the beaconing device's join
priority is its DAGRank(rank).

4.1.1.2. TSCH Slotframe and Link IE

The Slotframe and Link IE (FrameAndLinkIE) contains one or more
slotframes and their respective cells that a beaconing device
advertises to allow other devices to join the network.

6top re-uses this IE as defined in [IEEE802154e].

Format of a TSCH Slotframe and Link IE (FrameAndLinkIE).

```
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |    Length     |     SubID    |T|   NumFrame    |             |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+             |
  |                                                              |
  //               Slotframe and cell information               //
  |                                                              |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                           Figure 4

Length=variable

SubID=0x1b

T=0, i.e., short type

NumFrame is set to the total number of slotframe descriptors
contained in the TSCH Enhanced Beacon.

Format of a slotframe descriptor.

```
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |    FrameID     |              FrameLen          |   NumCell   |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                                                              |
  //          Cell information for each cell (5x NumCell)        //
  |                                                              |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                           Figure 5

The FrameID field shall be set to the slotframeHandle that uniquely
identifies the slotframe.

The FrameLen field shall be set to the size of the slotframe in
number of timeslots.

The NumCell field shall be set to the number of cells that belong to
the specific slotframe identified by the slotframeHandle.

Format of a Cell information.

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |         SlotOffset          |          ChannelOffset          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |  LinkOption   |
   +-+-+-+-+-+-+-+-+
```

                            Figure 6

SlotOffset shall be set to the slotOffset of this cell.

ChannelOffset shall be set to the channelOffset of this cell.

LinkOption indicates whether this cell is a TX cell, an RX cell, or a
SHARED TX cell, whether the device to which it is being linked is to
be used for clock synchronization, and whether this cell is hard
cell.

4.1.1.3. TSCH Timeslot Template IE

Timeslot Template IE (SlotTemplateIE) defines Timeslot template being
used by the TSCH device.

6top re-uses this IE as defined in [IEEE802154e].

Format of a TSCH Timeslot Template IE (SlotTemplateIE).

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |   Length      |    SubID    |T|  TemplateID   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                            Figure 7

Length=1

SubID=0x1c

T=0, i.e., short type

TemplateID shall be set to a Timeslot template handle. The full
timeslot template, which contains the macTimeslotTemplate of TSCH
(total 25 octets), MAY be included.(see [IEEE802154e]).

4.1.1.4. TSCH Channel Hopping IE

Channel Hopping IE (ChHoppingIE) defines the Hopping Sequence being
used by the TSCH device.

6top re-uses this IE as defined in [IEEE802154e].

Format of a TSCH Channel Hopping IE (ChHoppingIE).

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |      Length       | SubID |T| HopSequenceID |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                              Figure 8

Length=1

SubID=0x09

T=1, i.e., long type

HopSequenceID shall be set to a Hopping Sequence handle. The full
Hopping Sequence information MAY be included. (see [IEEE802154e]).

4.1.1.5. 6top Opcode IE

6top Opcode IE (OpcodeIE) defines operation codes of packets in 6top
sublayer.

This IE is not present in [IEEE802154e] and is defined by 6top.

Format of a 6top Opcode IE (OpcodeIE).

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |   Length     |   SubID   |T|   OpcodeID   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                              Figure 9

Length=1

SubID=0x41

   T=0, i.e., short type

   OpcodeID field shall be set to one of the following codes.

        0x00: Reserve Soft Cell Request

        0x01: Reserve Soft Cell Response

        0x02: Remove Soft Cell Request

        0x03: Reserve Hard Cell Request

        0x04: Remove Hard Cell Request

4.1.1.6. 6top Bandwidth IE

   Bandwidth IE (BwIE) defines the number of cells to be reserved or
   actually been reserved.

   This IE is not present in [IEEE802154e] and is defined by 6top.

   Format of a 6top Bandwidth IE (BwIE).

      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+
     | Length | SubID |T| FrameID | NumCell |
     +-+
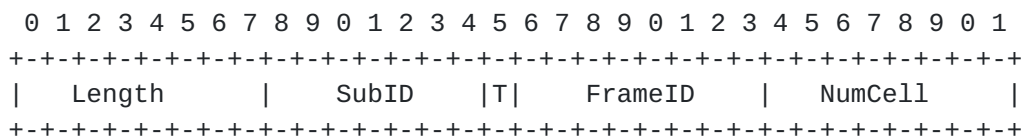
                              Figure 10

   Length=2

   SubID=0x42

   T=0, i.e., short type

   FrameID MAY be set to the SlotFrameHandle to identify the slotframe
   from which cells are reserved. FrameID field MAY be set to NOP,
   which means no specific slotframe is associated.

   NumCell shall be set to the number of cells. When BwIE is combined
   with the OpecodeID of Reserve Soft Cell Request, NumCell presents how
   many cells are required to reserve; and when BwIE is combined with
   the OpecodeID of Reserve Soft Cell Response, NumCell presents how
   many cells are reserved successfully.

4.1.1.7. 6top TrackID IE

   TrackID IE (TrackIdIE) describes the track which the reserved/removed
   cell(s) are associated with.

   This IE is not present in [IEEE802154e] and is defined by 6top.

   Format of a 6top TrackID IE (TrackIdIE).

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Length     |     SubID    |T|OwnerInstID|rev|              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+              |
   //                                                             //
   |                     TrackOwnerAddr                           |
   |                                                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
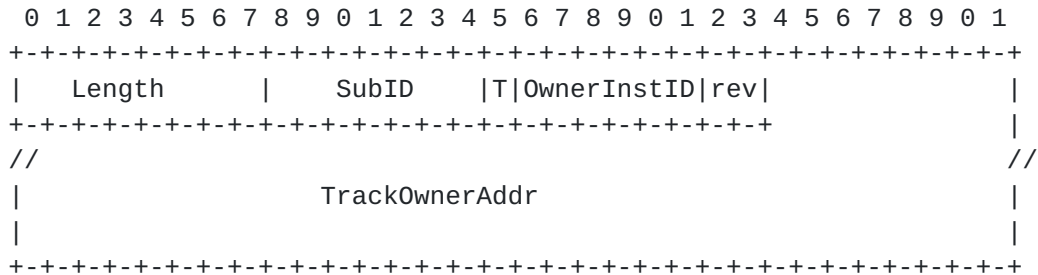
                             Figure 11

   Length=3 or 7. When length=3, TrackOwnerAddr is 2 bytes short
   address, and when length=7, TrackOwnerAddr is 6 bytes long address.

   SubID=0x43

   T=0, i.e., short type

   The combination of TrackOwnerAddr and OwnerInstId represents a
   specific TrackID.

4.1.1.8. 6top Generic Schedule IE

   Generic Schedule IE (ScheduleIE) describes cell sets. In different
   packets, ScheduleIE represents different information. See
   Section 4.1.2 for more detail.

   This IE is not present in [IEEE802154e] and is defined by 6top.

Format of a 6top Generic Schedule IE (ScheduleIE).

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Length     |    SubID    |T|                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                             |
   |                                                             |
   //                    Schedule Body                          //
   |                                                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
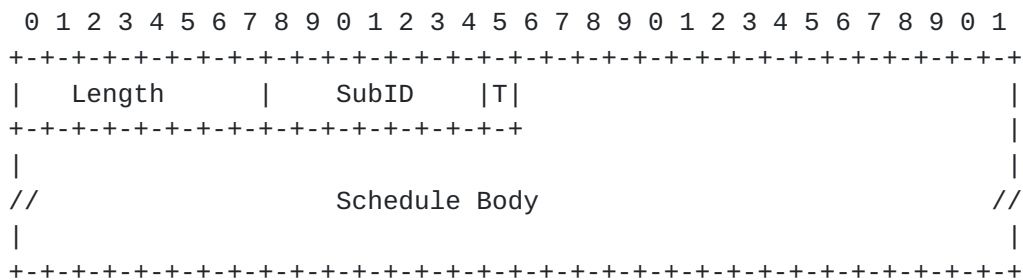
Figure 12

Length=variable

SubID=0x44

T=0, i.e., short type

Schedule Body carries one or more schedule object. An object MAY
carry a TLV (Type-Length-Value), which MAY itself comprise other
TLVs. TLV format is as follows. Type: 1 byte, Length: 1 byte,
Value: variable

The following are some examples of schedule object TLV.

Example 1. Cell Set TLV

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Type=1     |    Length    |    FrameID    |  NumCell    |F|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                             |
   //                      CellObjects                          //
   |                                                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 13

FrameID shall be set to the slotframeHandle that uniquely identifies
the slotframe.

NumCell shall be set to the number of cells that belong to the
specific slotframe identified by the slotframeHandle.

F=1 means the specified cells equals to what are listed in
CellObjects, and F=0 means the specified cells equals to what are not
listed in CellObjects.

CellObjects carries the information for one or more cells, including SlotOffset, ChannelOffset, LinkOption (Figure 6).

Example 2. Schedule Matrix TLV

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |   Type=2      |    Length     |   FrameID     |StartSlotOffset|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |StartSLotOffset|    NumSlot     |                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                               |
   |                                                               |
   //                   SlotBitMap (2x NumSlot)                   //
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 14

FrameID field MUST be set to the slotframeHandle that uniquely identifies the slotframe.

StartSlotOffset field (2 octets) MUST be set to the slotOffset in the specific slotframe identified by the slotframeHandle.

NumSlot field MUST be set to the number of timeslots from StartSlotOffset in the specific slotframe identified by the slotframeHandle.
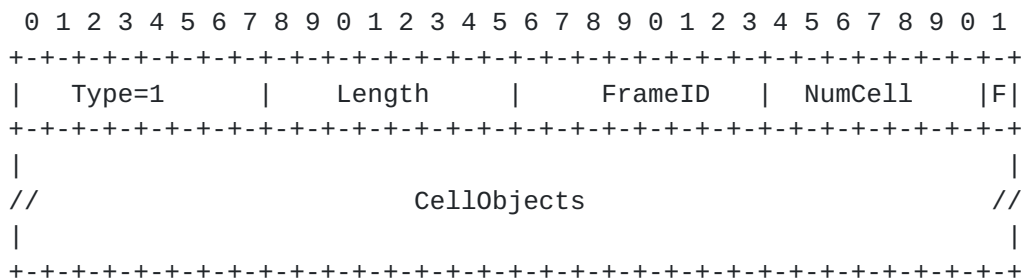
SlotBitMap (per timeslot) indicates for the given timeslot which channels are specified. For the 16 channels in 2.4GHz band, 2-octets are used to indicate which channel is specified. For example, given a timeslot and a SlotBitmap with value (10001000,00010000); the bitmap represents that ChannelOffset-0, ChannelOffset-4, ChannelOffset-11 are specified.

4.1.2. Packet Formats

This section describes the packets used in 6top to form a network, reserve/maintain bandwidth using soft cells, and reserve/remove hard cells in both the transmitter side and receiver sides. Each of these packets uses one or more IEs defined in Section 4.1.1.

4.1.2.1. TSCH Enhanced Beacon

The TSCH Enhanced Beacon is used to announce the presence of the network and allows new nodes to join. It is an Enhanced Beacon packet defined in [IEEE802154e] with the following Payload IEs:

TSCH Synchronization IE ([Section 4.1.1.1](#))

TSCH Timeslot Template IE ([Section 4.1.1.3](#))

TSCH Channel Hopping IE ([Section 4.1.1.4](#))

TSCH Slotframe and Link IE ([Section 4.1.1.2](#))

Payload IE of TSCH Enhanced Beacon Packet

```
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |       Length       |GroupID|T|             SyncIE            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                           SyncIE                             |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |          SyncIE            |          SlotTemplateIE          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |SlotTemplateIE |             ChHoppingIE                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                                                              |
     //                       FrameAndLinkIE                        //
     |                                                              |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
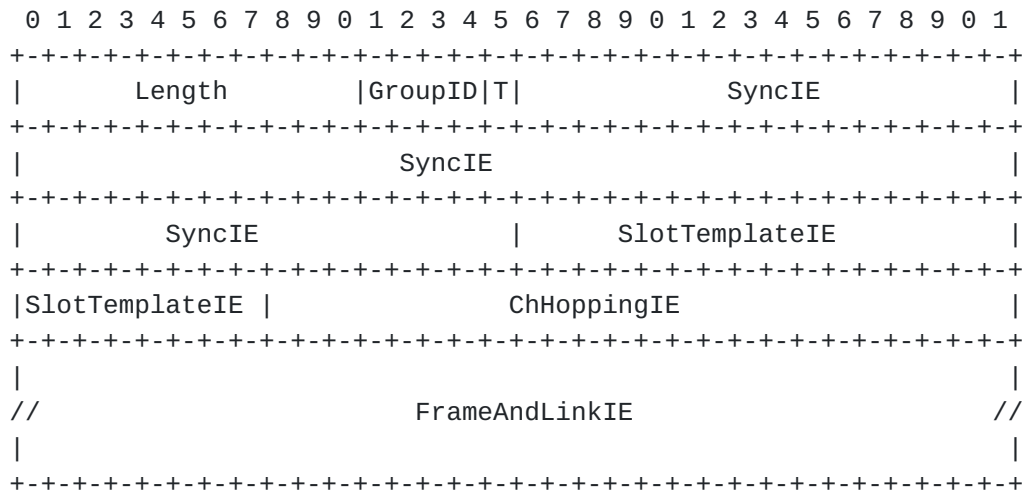
Figure 15

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

See [Section 4.1.1.1](#), [Section 4.1.1.3](#), [Section 4.1.1.4](#),[Section 4.1.1.2](#)
for SyncIE, SlotTemplateIE, ChHoppingIE and FrameAndLinkIE.

[4.1.2.2](#). Soft Cell Reservation Request

A Soft Cell Reservation Request packet is a DATA packet defined in
[[IEEE802154e](#)] with the following payload IE.

Payload IE of Soft Cell Reservation Request

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |       Length        |GroupID|T|            OpcodeIE           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | OpcodeIE     |                   BwIE                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    BwIE       |                                               |
   +-+-+-+-+-+-+-+-+                                               |
   //                          ScheduleIE                        //
   |                                                              |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                               Figure 16

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

The OpcodeID field in the 3-octet OpcodeIE SHOULD be set to 0x00,
indicates Reserve Soft Cell Request operation.

The NumCell field in 4-octet BwIE SHOULD be set to the number of
cells needed to be reserved.

The ScheduleIE specifies a candidate cell set, from which the cells
SHOULD be reserved. ScheduleIE MAY be empty, means there is no
constrain on which cells SHOULD not be reserved.

In addition, TrackIdIE can be added in the packet to associate the
reserved soft cells to a specific TrackID.

4.1.2.3. Soft Cell Reservation Response

Soft Cell Reservation Response is a DATA packet defined in
[IEEE802154e] with the following payload IE.

Payload IE of Soft Cell Reservation Response

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |        Length        |GroupID|T|           OpcodeIE           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | OpcodeIE    |                   BwIE                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    BwIE     |                                                 |
   +-+-+-+-+-+-+-+-+                                               |
   //                       ScheduleIE                          //
   |                                                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
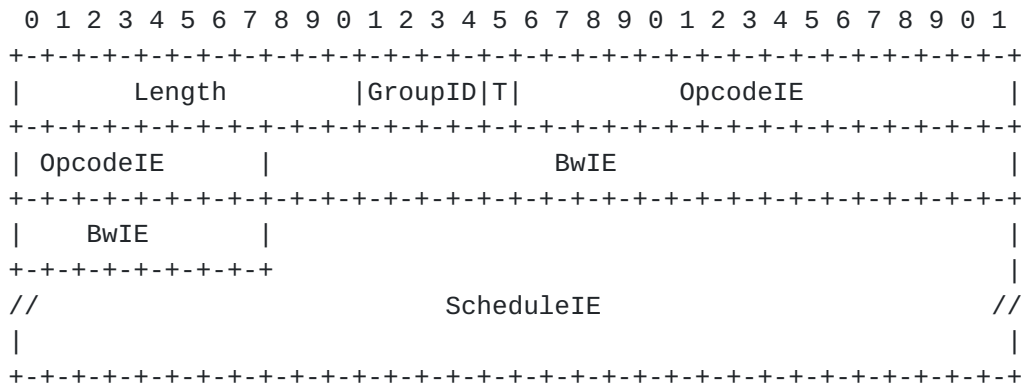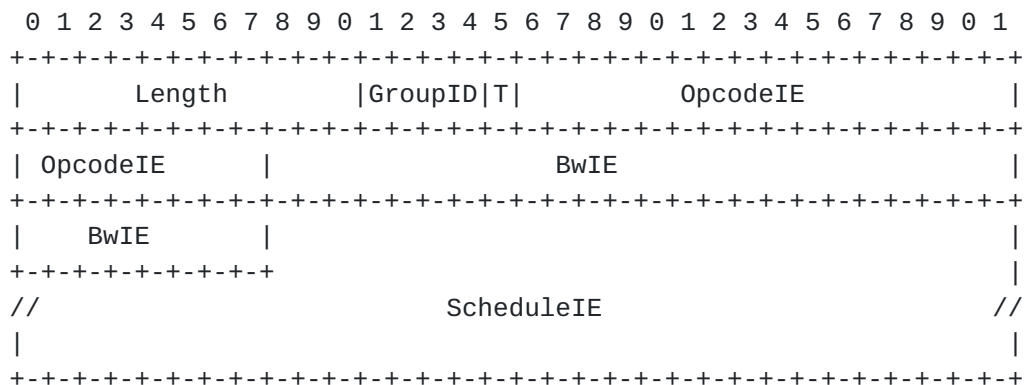
Figure 17

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

The OpcodeID field in the 3-octet OpcodeIE SHOULD be set to 0x01,
indicates Reserve Soft Cell Response operation.

The NumCell field in 4-octet BwIE SHOULD be set to the number of
cells which have been reserved successfully.

The ScheduleIE SHOULD specify all of the cells which have been
reserved successfully.

In addition, TrackIdIE can be added in the packet to associate the
reserved soft cells to a specific TrackID.

4.1.2.4. Soft Cell Remove Request

Soft Cell Remove Request is a DATA packet defined in [IEEE802154e]
with the following payload IE.

Payload IE of Soft Cell Remove Request

```
       0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |        Length         |GroupID|T|          OpcodeIE           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      | OpcodeIE      |                                               |
      +-+-+-+-+-+-+-+-+-+                                             |
      //                           ScheduleIE                        //
      |                                                               |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
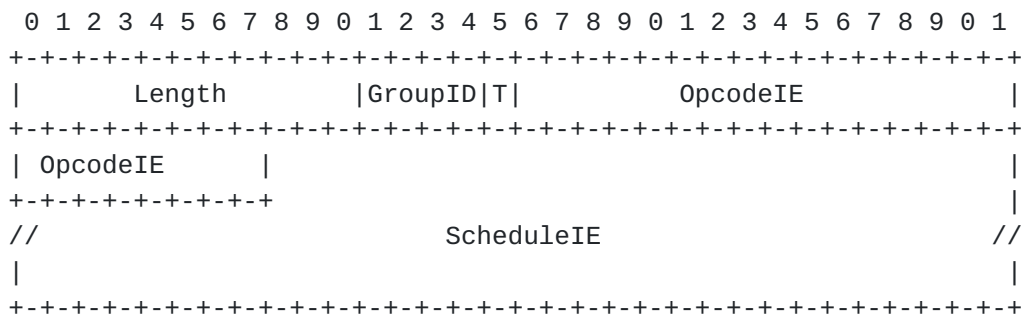
Figure 18

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

The OpcodeID field in the 3-octet OpcodeIE SHOULD be set to 0x02,
indicates Remove Soft Cell Request operation.

The ScheduleIE SHOULD specify all the cells that need to be removed.

4.1.2.5. Hard Cell Reservation Request

Hard Cell Reservation Request packet is a DATA packet defined in
[IEEE802154e] with the following payload IE.

Payload IE of Hard Cell Reservation Request

```
       0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |        Length         |GroupID|T|          OpcodeIE           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      | OpcodeIE      |                                               |
      +-+-+-+-+-+-+-+-+-+                                             |
      //                           ScheduleIE                        //
      |                                                               |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
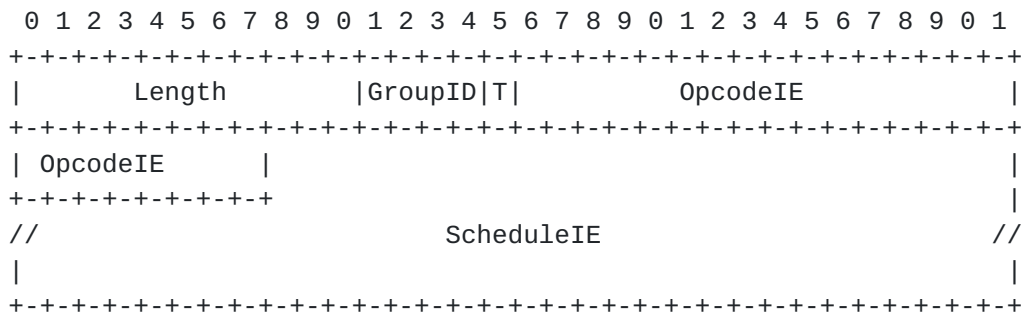
Figure 19

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

The OpcodeID field in the 3-octet OpcodeIE SHOULD be set to 0x03,
indicates Reserve Hard Cell Request operation.

The ScheduleIE SHOULD specify all the cell that need to be reserved.

In addition, TrackIdIE can be added in the packet to associate the
reserved hard cells to a specific TrackID.

4.1.2.6. Hard Cell Remove Request

Hard Cell Remove Request is a DATA packet defined in [IEEE802154e]
with the following payload IE.

Payload IE of Hard Cell Remove Request

```
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |       Length       |GroupID|T|          OpcodeIE            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | OpcodeIE      |                                             |
   +-+-+-+-+-+-+-+-+-+                                           |
   //                         ScheduleIE                       //
   |                                                            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
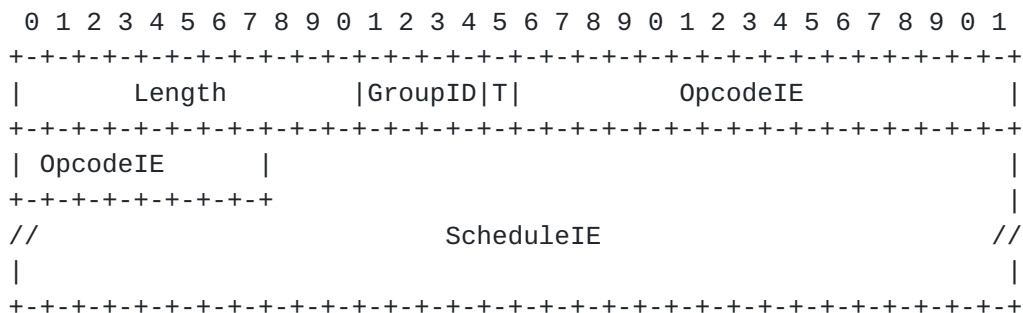
                            Figure 20

Length=variable

GroupID=0x1, i.e., MLME IE

T=1, i.e., payload IE

The OpcodeID field in the 3-octet OpcodeIE SHOULD be set to 0x04,
indicates Remove Hard Cell Request operation.

The ScheduleIE SHOULD specify all the cells that need to be removed.

4.2. Time Sequences

6top neighbors exchange 6top-specific packets in the following cases,
each detailed in a subsection.

        Network formation (Section 4.2.1)

        Creating soft cells (Section 4.2.2)

        Deleting soft cells ([Section 4.2.3](#))

        Maintaining soft cells ([Section 4.2.4](#))

        Creating hard cells ([Section 4.2.5](#))

        Deleting hard cells ([Section 4.2.6](#))

[4.2.1](#). Network Formation

   Network formation consists of two processes: joining and maintenance.

[4.2.1.1](#). Joining

   A node already in the network sends out TSCH Enhanced Beacons
   periodically.

   When a node is joining an existing network, it listens for TSCH
   Enhanced Beacons. After collecting one or more TSCH Enhanced BEACONs
   (the format of which is detailed in [Section 4.1.2.1](#)), the joining
   node MUST do the following.

        Initialize a neighbor table. Establish a neighbor table and
        record all of the information described in the TSCH Enhanced
        BEACONs as its initial schedule with those neighbors.

        Select a time source neighbor. According to the Joining
        Priority described by SyncIEs, the joining node chooses time
        source neighbors. 6top does not specify the criteria to choose
        time source neighbors from the Enhanced BEACONs.

        Select cells for Enhanced Beacons. The joining node selects
        one or more cells to indicate in its own Enhanced Beacons,
        which MAY be the same as the cells used by its neighbors for
        Enhanced Beacon broadcast, and record those cell(s) into the
        TSCH schedule with LinkType=ADVERTISING.

        Its Enhanced Beacons SHOULD include the cell(s) selected for EB
        purposes. The EB cells MUST be configured with LinkOption to
        "Receive" and "Timekeeping", telling its neighbors that the
        cell is used for broadcast.

        Start broadcasting Enhanced Beacon and communicate with
        neighbors.

4.2.1.2. Maintenance

Nodes MAY broadcast Enhance Beacons on the cells marked with
LinkType=ADVERTISING, and listen for Enhanced Beacons from neighbors
on the cells with LinkOptions "Receive" and "Timekeeping". If a cell
with LinkType=ADVERTISING has both the "Receive" and "Timekeeping"
LinkOptions set, which means that the cell is shared by neighbors and
itself for broadcasting, then broadcasting Enhanced Beacon has higher
priority.

Whenever a node receives an Enhanced Beacon, it SHOULD update its
schedule if there is a difference regarding to the cells used for
synchronizing with the advertiser of the Enhanced Beacon.

4.2.2. Creating soft cells

The upper layer instructs 6top to schedule one or more soft cells by
calling the Create soft cell command. This command can also be
called by the monitoring process internal to 6top.

When receiving a Create soft cell command, Node A's 6top sublayer
forms a Soft Cell Reservation Request packet which includes the BwIE
and ScheduleIE Information Elements. The BwIE indicates the number
of cells to be reserved (N1); the ScheduleIE indicates set of a
candidate cells from which the new cells SHOULD be selected. If the
ScheduleIE is empty, Node A indicates there is no constraint on cell
selection.

The Soft Cell Reservation Request is sent to the neighbor (Node B)
with whom new cells need to be scheduled. After receiving the Soft
Cell Reservation Request, Node B selects the cells from the candidate
cell set defined by the ScheduleIE in the Soft Cell Reservation
Request, and forms a Soft Cell Reservation Response packet. In the
Cell Reservation Response packet, the BwIE indicates the number of
cells actually being reserved (N2); the ScheduleIE indicates those
reserved cells. If N2 is smaller than N1, node B indicates to node A
that there are not enough qualified cells to be reserved. Node B
MUST record the reserved cells into its local schedule when sending
the Soft Cell Reservation Response. After receiving the Soft Cell
Reservation Response, Node A MUST record the reserved cells into its
local schedule.

The policy to build a candidate cell set and the policy to select
cells from the candidate cell set to reserve are out of scope.

The format of Schedule Body is flexible. For example, Node A can use
Cell Set TLV defined in Figure 13 with field 'F' set to '0', and the
CellObjects includes all of the cells being used by Node A. In

another word, the cell candidate set is all of the cells not being
included in the list defined by CellObjects.

The behavior of the nodes when the soft cells negotiation fails is
out of scope.

4.2.3. Deleting soft cells

The upper layer instructs 6top to delete one or more soft cells by
calling the Delete soft cell command (Section 3.1.6). This command
can also be called by the monitoring process internal to 6top
(Section 6).

When receiving a Delete soft cell command, Node A's 6top sublayer
selects cells to be removed from its local schedule, and creates a
Soft Cell Remove Request, which includes a ScheduleIE Information
Element. The ScheduleIE indicates which specific cells to remove
with a neighbor (Node B). The cells specified in the ScheduleIE
SHOULD be removed from local schedule of Node A when the Soft Cell
Remove Request is sent to Node B. When receiving the Soft Cell
Remove Request, the cells specified in the ScheduleIE SHOULD be
removed from the local schedule of Node B.

The policy to select cells corresponding to a Delete soft cell
command is out of scope.

4.2.4. Maintaining soft cells

The monitoring process internal to 6top (Section 6) is responsible
for monitoring and re-scheduling soft cells to meet some QoS
requirements. The monitoring process MAY issue a soft cell
Maintenance command, which indicate a set of cells to be re-allocated
in the TSCH schedule.

When receiving a soft cell Maintenance command, 6top initializes a
Soft Cell Remove Request (Section 4.2.3) with the neighbor in
question, followed by a Soft Cell Reservation Request
(Section 4.2.2).

4.2.5. Creating hard cells

The upper layer instructs 6top to create one or more hard cells by
calling the Create hard cell command.

When receiving a Create hard cell command, Node A's 6top sublayer
creates a Hard Cell Reservation Request, including a ScheduleIE. The
ScheduleIE indicates which specific cells with a neighbor (Node B) to
be added. The cells specified in the ScheduleIE SHOULD be added in

local schedule of Node A while the Hard Cell Reserve Request is sent
to Node B. When receiving the Hard Cell Reserve Request, the cells
specified in the ScheduleIE SHOULD be added in the local schedule of
Node B.

4.2.6. Deleting hard cells

The upper layer instructs 6top to delete one or more hard cells by
calling the Delete hard cell command.

When receiving a Delete hard cell command, Node A's 6top sublayer
creates a Hard Cell Remove Request, including a ScheduleIE. The
ScheduleIE indicates which specific cells with a neighbor (Node B) to
be removed. The cells specified in the ScheduleIE SHOULD be removed
from local schedule of Node A while the Hard Cell Remove Request is
sent to Node B. When receiving the Hard Cell Remove Request, the
cells specified in the ScheduleIE SHOULD be removed from the local
schedule of Node B.

5. Statistics

The 6top Statistics Function (SF) is responsible for collecting
statistics, which it can provide to an upper layer and the Monitoring
Function (Section 6).

5.1. Statistics Metrics

6top is in charge of keeping statistics from a set of metrics
gathered from the behavior of the TSCH layer.

The statistics data related to node states and cell metrics SHOULD be
provided to upper layer for management, e.g., for RPL to calculate
the node's Rank or for GMPLS to the required bandwidth is met. The
specific algorithm to generate the statistics is out of scope.
However, the statistics component SHOULD include the following
metrics:

1. LinkThroughput: associated with a link, Node A->Node B. For
    example, LinkThroughput can be calculated with:
    SUM(NumOfCell(i)*NumOfBytePerPacket)/(FrameLen(i)*SlotDuration)
    where NumOfCell(i) is the total number of cells from Node A to
    Node B in Slotframe-i, FrameLen(i) is the length of Slotframe-i.
    The unit is Byte/second.

2. Latency: associated with a link, Node A->Node B. For example,
    latency can be expressed as Minimum and Maximum Latency. Minimum
    Latency = Min(MinNumOfSlot(i),i=1..) * SlotDuration and Maximum
    Latency = Max(MaxNumOfSlot(i),i=1..) * SlotDuration where,

MinNumOfSlot(i) and MaxNumOfSlot(i) are the minimum or maximum
number of timeslots between two dedicated cells from Node A to
Node B in Slotframe-i, respectively.

3. LinkQuality. For example, average LQI, ETX, PDR, RSSI.

4. TrafficLoad. For example, Queue Full Rate, Queue Empty Rate.

5. NodeEnergy. For example, $E\_E=E\_bat / [E\_0 (T-t)/T]$.

5.2. Statistics Configuration

The Statistics Function SHOULD be configurable. The configuration
parameters SHOULD include:

LinkQualityStatisticsEn

TafficLoadStatisticsEn

DeviceStatisticsEn

6top statistics function is enabled/disabled and configured by the
commands defined in Section 3.4

6. Monitoring

The 6top Monitoring Function (MF) is responsible for monitoring cell
quality, traffic load, and issuing soft cell Maintenance commands, or
Create/Delete soft cell commands. The data provided by the
Statistics Function MAY be used as an input of MF in taking a
monitoring decision.

6.1. Monitor Configuration

Monitoring Function SHOULD be configurable. The configuration
parameters SHOULD include:

MaintainCellEn.

CreateDeleteCellEn.

QosLevel. QosLevel SHOULD associate with specific neighbor
address. QosLevel MAY reflect the latency constraint, cell
quality constraint, and so on. The value of QosLevel works as
the bandwidth redundancy coefficient.

The 6top monitoring function is enabled/disabled and configured by
the commands defined in Section 3.3

6.2. Actuation

The cell quality statistics MAY be used to generate soft a cell
Maintenance command, which triggers a soft cell Maintenance procedure
(see Section 4.2.4). The traffic load statistics MAY be used to
generate internal Create (resp. Delete) soft cell commands, which
trggiers a soft cell Reservation (resp. Remove) process (see
Section 4.2.2 and Section 4.2.3).

The policy to generate the soft cell Maintenance command and the
policy to generate Create/Delete soft cell commands is out of scope.

The policy to generate Create/Delete soft cell commands MAY take
QosLevel into account. For example, there are two slotframes
existing, Slotframe-1 consists of 32 timeslots, Slotframe-2 consists
of 96 timeslots; timeslot duration is 10ms; QosLevel=1.5. If, from
the traffic load statistics, MF determines that 2 packet/second
SHOULD be added, then the MF generates a Create soft cell command,
where FrameID=2, NumCell=3.

7. References

7.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
           Requirement Levels", BCP 14, RFC 2119, March 1997.

7.2. Informative References

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