          PCEP Extensions for LSP scheduling with stateful PCE
            draft-zhuang-pce-stateful-pce-lsp-scheduling-05

Abstract

   This document proposes a set of extensions needed to the stateful
   Path Computation Element (PCE) communication Protocol (PCEP), so as
   to enable Labeled Switched Path (LSP) scheduling for path computation
   and LSP setup/deletion based on the actual network resource usage
   duration of a traffic service in a centralized network environment as
   stated in [I.D.ietf-teas-scheduled-resources].

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1. Introduction

   The Path Computation Element Protocol (PCEP) defined in [RFC5440] is
   used between a Path Computation Element (PCE) and a Path Computation
   Client (PCC) (or other PCE) to enable computation of Multi-protocol
   Label Switching (MPLS) for Traffic Engineering Label Switched Path
   (TE LSP).

   Further, in order to support use cases described in [I-D.ietf-pce-
   stateful-pce-app], [I-D.ietf-pce-stateful-pce] specifies a set of
   extensions to PCEP to enable stateful control of MPLS-TE and GMPLS
   LSPs via PCEP.

   Traditionally, the usage and allocation of network resources,
   especially bandwidth, can be supported by a Network Management System
   operation such as path pre-establishment. However, this does not
   provide efficient network usage since the established paths exclude
   the possibility of being used by other services even when they are
   not used for undertaking any service. [I-D.ietf-teas-scheduled-
   resources] then provides a framework that describes and discusses the
   problem and propose an appropriate architecture for the scheduled
   reservation of TE resources.

   With the scheduled reservation of TE resources, it allows network
   operators to reserve resources in advance according to the agreements
   with their customers, and allow them to transmit data with scheduling
   such as specified starting time and duration, for example for a
   scheduled bulk data replication between data centers. It enables the
   activation of bandwidth usage at the time the service really being
   used while letting other services obtain it in spare time. The
   requirement of scheduled LSP provision is mentioned in [I-D.ietf-pce-
   stateful-pce-app] and [RFC7399], so as to provide more efficient
   network resource usage for traffic engineering, which hasn't been
   solved yet. Also, for deterministic networks, the scheduled LSP can
   provide a better network resource usage for guaranteed links. This
   idea can also be applied in segment routing to schedule the network
   resources over the whole network in a centralized manner as well.

   With this in mind, this document proposes a set of extensions needed
   to the stateful PCE, so as to enable LSP scheduling for path
   computation and LSP setup/deletion based on the actual network
   resource usage duration of a traffic service. A scheduled LSP is
   characterized by a starting time and a duration. When the end of the
   LSP life is reached, it is deleted to free up the resources for other
   LSP (scheduled or not).

2. Conventions used in this document

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

2.1. Terminology

The following terminologies are re-used from existing PCE documents.

o Active Stateful PCE [I-D.ietf-pce-stateful-pce];

o Delegation [I-D.ietf-pce-pce-initiated-lsp];

o PCC [RFC5440], [I-D.ietf-pce-stateful-pce];

o PCE [RFC5440], [I-D.ietf-pce-stateful-pce];

o TE LSP [RFC5440], [I-D.ietf-pce-stateful-pce];

o TED [RFC5440], [I-D.ietf-pce-stateful-pce];

o LSP DB [RFC5440], [I-D.ietf-pce-stateful-pce];

In addition, this document defines the following terminologies.

Scheduled TE LSP: a LSP with the scheduling attributes,that carries traffic flow demand at an starting time and last for a certain duration. The PCE operates path computation per LSP availability at the required time and duration.

Scheduled LSP DB: a database of scheduled LSPs

Scheduled TED: Traffic engineering database with the awareness of scheduled resources for TE. This database is generated by the PCE from the information in TED and scheduled LSP DB and allows knowing, at any time, the amount of available resources (does not include failures in the future).

Starting time(start-time): This value indicates when the scheduled LSP is used and the corresponding LSP must be setup and active. In other time(i.e., before the starting time or after the starting time plus Duration), the LSP can be inactive to include the possibility of the resources being used by other services.

Duration: The value indicates the time duration that the LSP is undertaken by a traffic flow and the corresponding LSP must be

setup and active. At the end of which, the LSP is teardown and
removed from the data base.

3. Motivation and Objectives

A stateful PCE can support better efficiency by using LSP scheduling
described in the use case of [I-D.ietf-pce-stateful-pce]. This
requires the PCE to maintain the scheduled LSPs and their associated
resource usage, e.g. bandwidth for Packet-switched network, as well
as the ability to trigger signaling for the LSP setup/tear-down at
the correct time.

Note that existing configuration tools can be used for LSP
scheduling, but as highlighted in section 3.1.3 of [I-D.ietf-pce-
stateful-pce] as well as discussions in [I-D.ietf-teas-scheduled-
resources], doing this as a part of PCEP in a centralized manner, has
obvious advantages.

The objective of this document is to provide a set of extensions to
PCEP to enable LSP scheduling for LSPs creation/deletion under the
stateful PCE control, according to traffic services from customers,
so as to improve the usage of network resources.

4. Architecture Overview

4.1. LSP scheduling Overview

The LSP scheduling allows PCEs and PCCs to provide scheduled LSP for
customers' traffic services at its actual usage time, so as to
improve the network resource efficient utilization.

For stateful PCE supporting LSP scheduling, there are two types of
LSP databases used in this document. One is the LSP-DB defined in
PCEP [I-D.ietf-pce-stateful-pce], while the other is the scheduled
LSP database (SLSP- DB, see section 6). The SLSP-DB records
scheduled LSPs and is used as a complementary to the TED and LSP-DB.
Note that the two types of LSP databases can be implemented in one
physical database or two different databases. This document does not
state any preference here.

Furthermore, a scheduled TED can be generated from the scheduled LSP
DB, LSP DB and TED to indicate the network links and nodes with
resource availability information for now and future. The scheduled
TED should be maintained by all PCEs within the network environment.

In case of implementing PCC-initiated scheduled LSPs, a PCC can
request a path computation with LSP information of its scheduling
parameters, including the starting time and the duration. Upon

receiving the request with the scheduled LSP delegation, a stateful
PCE SHALL check the scheduled TED for the network resource
availability on network nodes and computes a path for the LSP with
the scheduling information.

For a multiple PCE environment, in order to coordinate the scheduling
request of the LSP path over the network, the PCE needs to send a
requestmessage with the path information as well as the scheduled
resource for the scheduled LSP to other PCEs within the network, so
as to coordinate with their scheduled LSP DBs and scheduled TEDs.
Once other PCEs receive the request message with the scheduled LSPs
information, if not conflicting with their scheduled LSP DBs, they
reply to the requesting PCE with a response message carrying the
scheduled LSP and update their scheduled LSP DBs and scheduled TEDs.
After the requesting PCE confirms with all PCEs, the PCE SHALL add
the scheduled LSP into its scheduled LSP Database and update its
scheduled TED.

Then the stateful PCE can response to the PCC with the path for the
scheduled LSP to notify the result of the computation. However, the
PCC should not signal the LSP over the path once receiving these
messages since the path is not activated yet until its starting time.

Alternatively, the service can also be initiated by PCE itself. In
case of implementing PCE-initiated scheduled LSP, the stateful PCE
shall check the network resource availability for the traffic and
computes a path for the scheduled LSP per request in the same way as
in PCC- Initiated mode and then for a multiple PCE network
environment, coordinate the scheduled LSP with other PCEs in the
network in the same way as in the PCC-Initiated mode.

In both modes, for activation of scheduled LSPs, the stateful PCE can
send a path computation LSP Initiate (PCInitiate message) with LSP
information at its starting time to the PCC for signaling the LSP
over the network nodes as defined in [I-D.ietf-pce-pce- initiated-
lsp]. Also, in the PCC-initiated mode, with scheduling information
,the PCC can activate the LSP itself by triggering over the path at
its starting time as well. When the scheduling usage expires, active
stateful PCE SHALL remove the LSP from the network , as well as
notify other PCEs to delete the scheduled LSP from the scheduled LSP
database.

4.2. Support of LSP Scheduling

4.2.1. LSP Scheduling

   For a scheduled LSP, a user configures it with an arbitrary
   scheduling duration time Ta to time Tb, which may be represented as
   [Ta, Tb].

   When an LSP is configured with arbitrary scheduling duration [Ta,
   Tb], a path satisfying the constraints for the LSP in the scheduling
   duration is computed and the LSP along the path is set up to carry
   traffic from time Ta to time Tb.

4.2.2. Periodical LSP Scheduling

   In addition to LSP Scheduling at an arbitrary time period, there are
   also periodical LSP Scheduling.

   A periodical LSP Scheduling represents Scheduling LSP every time
   interval. It has a scheduling duration such as [Ta, Tb], a number of
   repeats such as 10 (repeats 10 times), and a repeat cycle/time
   interval such as a week (repeats every week). The scheduling
   interval: "[Ta, Tb] repeats n times with repeat cycle C" represents
   n+1 scheduling intervals as follows:

   [Ta, Tb], [Ta+C, Tb+C], [Ta+2C, Tb+2C], ..., [Ta+nC, Tb+nC]

   When an LSP is configured with a scheduling interval such as "[Ta,
   Tb] repeats 10 times with a repeat cycle a week" (representing 11
   scheduling intervals), a path satisfying the constraints for the LSP
   in each of the scheduling intervals represented by the periodical
   scheduling interval is computed and the LSP along the path is set up
   to carry traffic in each of the scheduling intervals.

4.2.2.1. Elastic Time LSP Scheduling

   In addition to the basic LSP scheduling at an arbitrary time period,
   another option is elastic time intervals, which is represented as
   within -P and Q, where P and Q is an amount of time such as 300
   seconds. P is called elastic range lower bound and Q is called
   elastic range upper bound.

   For a simple time interval such as [Ta, Tb] with an elastic range,
   elastic time interval: "[Ta, Tb] within -P and Q" means a time period
   from (Ta+X) to (Tb+X), where -P <= X <= Q. Note that both Ta and Tb
   may be shifted the same X.

   When an LSP is configured with elastic time interval "[Ta, Tb] within
   -P and Q", a path is computed such that the path satisfies the
   constraints for the LSP in the time period from (Ta+X) to (Tb+X)

and |X| is the minimum value from 0 to max(P, Q). That is that
[Ta+X, Tb+X] is the time interval closest to time interval [Ta, Tb]
within the elastic range. The LSP along the path is set up to carry
traffic in the time period from (Ta+X) to (Tb+X).

Similarly, for a recurrent time interval with an elastic range,
elastic time interval: "[Ta, Tb] repeats n times with repeat cycle C
within -P and Q" represents n+1 simple elastic time intervals as
follows:

[Ta+X0, Tb+X0], [Ta+C+X1, Tb+C+X1], ..., [Ta+nC+Xn, Tb+nC+Xn]
                        where -P <= Xi <= Q, i = 0, 1, 2, ..., n.

If a user wants to keep the same repeat cycle between any two
adjacent time intervals, elastic time interval: "[Ta, Tb] repeats n
times with repeat cycle C within -P and Q SYNC" may be used, which
represents n+1 simple elastic time intervals as follows:

[Ta+X, Tb+X], [Ta+C+X, Tb+C+X], ..., [Ta+nC+X, Tb+nC+X]
                        where -P <= X <= Q.

4.2.2.2. Graceful Periods

Besides the stated time scheduling, a user may want to have some
graceful periods for each or some of the time intervals for the LSP.
Two graceful periods may be configured for a time interval. One is
the graceful period before the time interval, called grace-before,
which extends the lifetime of the LSP for grace-before (such as 30
seconds) before the time interval. The other is the one after the
time interval, called grace-after, which extends the lifetime of the
LSP for grace-after (such as 60 seconds) after the time interval.

When an LSP is configured with a simple time interval such as [Ta,
Tb] with graceful periods such as grace-before GB and grace-after GA,
a path is computed such that the path satisfies the constraints for
the LSP in the time period from Ta to Tb. The LSP along the path is
set up to carry traffic in the time period from (Ta-GB) to (Tb+GA).
During graceful periods from (Ta-GB) to Ta and from Tb to (Tb+GA),
the LSP is up to carry traffic (maybe in best effort).

4.2.3. Stateful PCE Capability TLV

After a TCP connection for a PCEP session has been established, a PCC
and a PCE indicates its ability to support LSP scheduling during the
PCEP session establishment phase. For a multiple-PCE environment,
the PCEs should also establish PCEP session and indicate its ability
to support LSP scheduling among PCEP peers. The Open Object in the
Open message contains the STATEFUL-PCE-CAPABILITY TLV defined in [I-

D.ietf-pce-stateful-pce]. Note that the STATEFUL- PCE-CAPABILITY TLV
is defined in [I-D.ietf-pce-stateful- pce] and updated in [I-D.ietf-
pce-pce-initiated-lsp] and [I-D.ietf- pce-stateful-sync-
optimizations]. In this document, we define a new flag bit B (SCHED-
LSP-CAPABLITY) flag for the STATEFUL- PCE-CAPABILITY TLV to indicate
the support of LSP scheduling and another flag bit PD (PD-LSP-
CAPABLITY) to indicate the support of LSP periodical scheduling.

   B (LSP-SCHEDULING-CAPABILITY - 1 bit): If set to 1 by a PCC, the B
      Flag indicates that the PCC allows LSP scheduling; if set to 1 by
      a PCE, the B Flag indicates that the PCE is capable of LSP
      scheduling. The B bit MUST be set by both PCEP peers in order to
      support LSP scheduling for path computation.

   PD (PD-LSP-CAPABLITY - 1 bit): If set to 1 by a PCC, the PD Flag
      indicates that the PCC allows LSP scheduling periodically; if set
      to 1 by a PCE, the PD Flag indicates that the PCE is capable of
      periodical LSP scheduling. The PD bit MUST be set by both PCEP
      peers in order to support periodical LSP scheduling for path
      computation.

4.3. Scheduled LSP creation

   In order to realize PCC-Initiated scheduled LSP in a centralized
   network environment, a PCC has to separate the setup of a LSP into
   two steps. The first step is to request and get a LSP but not signal
   it over the network. The second step is to signal the scheduled LSP
   over the LSRs (Labeled switched Router) at its starting time.

   For PCC-Initiated scheduled LSPs, a PCC can send a path computation
   request (PCReq) message (see section 4.3.1) or a path computation LSP
   report (PCRpt) message (see section 4.3.1) including its demanded
   resources with the scheduling information and delegation to a
   stateful PCE.

   Upon receiving the delegation via PCRpt message, the stateful PCE
   computes the path for the scheduled LSP per its starting time and
   duration based on the network resource availability stored in
   scheduled TED (see section 4.1).

   If a resultant path is found, the stateful PCE will send a PCReq
   message with the path information as well as the scheduled resource
   information for the scheduled LSP to other PCEs within the network if
   there is any, so as to keep their scheduling information
   synchronized.

   Once other PCEs receive the PCReq message with the scheduled LSP, if
   not conflicts with their scheduled LSP DBs, they will reply to the

requesting PCE with a PCRep message carrying the scheduled LSP and update their scheduled LSP DBs and scheduled TEDs. After the requesting PCE confirms with all PCEs, the PCE SHALL add the scheduled LSP into its scheduled LSP DB and update its scheduled TED. If conflicts happen or no path available is found, the requesting PCE SHALL return a PCRep message with NO PATH back to the PCC. Otherwise, the stateful PCE will send a PCRep message or PCUpd message (see section 4.3.3) with the path information back to the PCC as confirmation.

For PCE-Initiated Scheduled LSP, the stateful PCE can compute a path for the scheduled LSP per requests from network management systems automatically based on the network resource availability in the scheduled TED and coordinate with other PCEs on the scheduled LSP in the same way as in the PCC- Initiated mode.

In both modes:

o   the stateful PCE is required to update its local scheduled LSP DB and scheduled TED with the scheduled LSP. Besides, it shall send a PCReq message with the scheduled LSP to other PCEs within the network, so as to achieve the scheduling traffic engineering information synchronization.

o   Upon receiving the PCRep message or PCUpd message for scheduled LSP from PCEs with a found path, the PCC knows that it gets a scheduled path for the LSP but not trigger signaling for the LSP setup on LSRs.

o   In any case, stateful PCE can update the Scheduled LSP parameters on any network events using the PCUpd message to PCC as well as other PCEs.

o   When it is time (i.e., at the start time) for the LSP to be set up, the delegated PCE sends a PCEP Initiate request to the head end LSR providing the path to be signaled.

4.3.1. The PCReq message and PCRpt Message

After scheduled LSP capability negotiation, for PCC-Initiated mode, a PCC can send a PCReq message or a PCRpt message including the SCHED-LSP- ATTRIBUTE TLV (see section 4.3.4.1) or SCHED-PD-LSP-ATTRIBUTE TLV (see section 4.3.4.2) carried in the LSP Object (see section 4.3.4) body to indicate the requested LSP scheduling parameters for a customer's traffic service with the delegation bit set to 1 in LSP Object. The value of requested bandwidth is taken via the existing 'Requested Bandwidth with BANDWIDTH Object- Type as 1' defined in [RFC5440].

Meanwhile, for both modes (PCC-Initiated and PCE-Initiated), the
delegated PCE shall distribute the scheduling information to other
PCEs in the environment by sending a PCReq message with the SCHED-
LSP-ATTRIBUTE TLV or SCHED-PD-LSP-ATTRIBUTE TLV, as well as the
Bandwith Object and RRO for the found path.

The definition of the PCReq message and PCRpt message to carry LSP
objects (see [I- D.ietf-pce-stateful-pce]) remains unchanged.

4.3.2. The PCRep Message

To provide scheduled LSP for TE-LSPs, the stateful PCE SHALL compute
the path for the scheduled LSP carried on PCReq message based on
network resource availability recorded in scheduled TED which is
generated from the scheduled LSP-DB and TED and also synchronize the
scheduling with other PCEs in the environment by using PCReq message
with path and resource information for the scheduled LSP.

If no conflict exists, other PCEs SHALL send a PCRep message with the
SCHED-LSP-ATTRIBUTE TLV or SCHED-PD-LSP-ATTRIBUTE TLV, as well as the
Bandwith Object and RRO back to the requesting PCE.

If the LSP request can be satisfied and an available path is found,
the stateful PCE SHALL send a PCRep Message including the SCHED- LSP-
ATTRIBUTE TLV or SCHED-PD-LSP-ATTRIBUTE TLV in the LSP Object body,
as well as the Bandwith Object and RRO for the found path back to the
PCC as a successful acknowledge.

If conflicts happen or no path available is found, the requesting PCE
SHALL return a PCRep message with NO PATH back to the PCC.

4.3.3. The PCUpd Message

To provide scheduled LSP for TE-LSPs, the stateful PCE SHALL compute
the path for the scheduled LSP carried on PCRpt message based on
network resource availability recorded in scheduled TED which is
generated from the scheduled LSP-DB, LSP DB and TED.

If the request can be satisfied and an available path is found, the
stateful PCE SHALL send a PCUpd Message including the SCHED- LSP-
ATTRIBUTE TLV or SCHED-PD-LSP-ATTRIBUTE TLV in the LSP Object body to
the PCC Note that, the stateful PCE can update the Scheduled LSP
parameters later as well based on any network events using the same
PCUpd message.

If conflicts happen or no path available is found, the requesting PCE
SHALL return a PCUpd message with ERO empty.

4.3.4. LSP Object

The LSP object is defined in [I-D.ietf-pce-stateful-pce]. This
document add an optional SCHED-LSP-ATTRIBUTE TLV for normal LSP
scheduling and an optional SCHED-PD-LSP-ATTRIBUTE TLV for periodical
LSP scheduling.

The presence of SCHED-LSP-ATTRIBUTE TLV in the LSP object indicates
that this LSP is requesting scheduled parameters while the SCHED-PD-
LSP-ATTRIBUTE TLV indicates that this scheduled LSP is periodical.
The scheduled LSP attribute TLV MUST be present in LSP Object for
each scheduled LSP carried in the PCReq message, the PCRpt message
and the PCUpd message. For periodical LSPs, the SCHED-PD-LSP-
ATTRIBUTE TLV can be used in LSP Object.

4.3.4.1. SCHED-LSP-ATTRIBUTE TLV

The SCHED-LSP-ATTRIBUTE TLV can be included as an optional TLV within
the LSP object for LSP scheduling for the requesting traffic service.

This TLV SHOULD be included only if both PCEP peers have set the B
(LSP-SCHEDULING-CAPABILITY bit) in STATEFUL-PCE-CAPABILITY TLV
carried in open message.

The format of the SCHED-LSP-ATTRIBUTE TLV is shown in the following
figure:

```
 0                   1                   2                   3
 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               |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Start-Time (minutes)                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Duration (minutes)                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
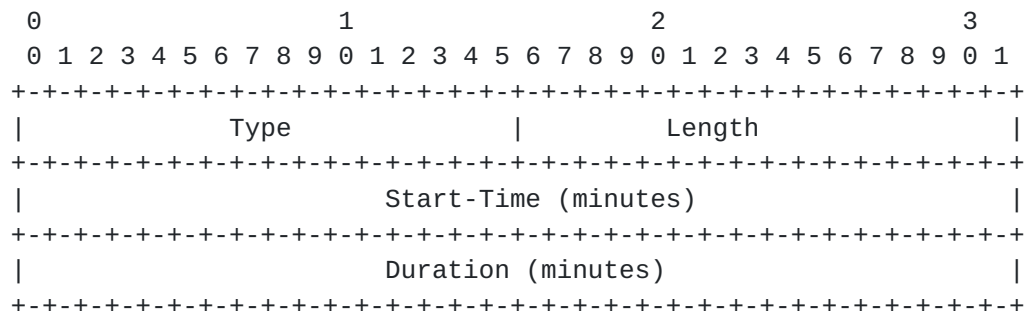
The type of the TLV is [TBD] and it has a fixed length of 8 octets.

The fields in the format are:

Start-Time (32 bits): This value in minutes, indicates when the
   scheduled LSP is used to carry traffic and the corresponding LSP
   must be setup and activated.

Duration (32 bits): The value in minutes, indicates the duration
   that the LSP is undertaken by a traffic flow and the corresponding

LSP must be up to carry traffic. At the expiry of this duration,
the LSP is tear down and deleted.

Note, that the values of starting time and duration is from the
perspective of the PCEP peer that is sending the message, also note
the unit of time is minutes, and thus the time spent on transmission
on wire can be easily ignored.

Editor Note 1: As described in [I-D.zhuang-teas-scheduled-
resources],the encoding of the resource state information could also
be expressed as a start time and end time. Multiple periods,
possibly of different lengths, may be associated with one reservation
request, and a reservation might repeat on a regular cycle.

Editor Notes2: The time stated in this section and in section 4.3.4.2
may be a relative time or an absolute time, which need more
discussions.

Editor Note3: the elastic interval and graceful interval may also be
applied to the random LSP scheduling which need more discussion.

4.3.4.2. SCHED-PD-LSP-ATTRIBUTE TLV

The periodical LSP is a special case of LSP scheduling. The traffic
service happens in a series of repeated time intervals. The SCHED-
PD-LSP-ATTRIBUTE TLV can be included as an optional TLV within the
LSP object for this periodical LSP scheduling.

This TLV SHOULD be included only if both PCEP peers have set the B
(LSP-SCHEDULING-CAPABILITY bit) and PD (PD-LSP-CAPABLITY bit) in
STATEFUL-PCE-CAPABILITY TLV carried in open message.

The format of the SCHED-PD-LSP-ATTRIBUTE TLV is shown in the
following figure:

```
     0                   1                   2                   3
     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 (3)           |             Length            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                           Start-Time                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                           Duration                            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Repeat-time-length                      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Options |        Number-repeats       |        Reserved (0)    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                 GrB            |             GrA         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |      Elastic-Lower-Bound     |       Elastic-Upper-Bound      |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Start-Time (32 bits): This value in minutes, indicates the time when
      the scheduled LSP is used to carry traffic and the corresponding
      LSP must be setup and activated.

   Duration (32 bits): The value in minutes, indicates the duration
      that the LSP is undertaken by a traffic flow and the corresponding
      LSP must be up to carry traffic.

   Repeat-time-length: The time length in minutes after which LSP
      starts to carry traffic again for (Start Time-End Time).

   Options: Indicates a way to repeat.

        Options = 1: repeat every day;

        Options = 2: repeat every week;

        Options = 3: repeat every month;

        Options = 4: repeat every year;

        Options = 5: repeat every Repeat-time-length.

   Number-repeats: The number of repeats. In each of repeats, LSP
      carries traffic.

   In addition, it contains an non zero grace-before and grace-after if
   graceful periods are configured. It includes an non zero elastic
   range lower bound and upper bound if there is an elastic range
   configured.

   o GrB (Grace-Before): The graceful period time length in seconds
      before the starting time.

   o GrA (Grace-After): The graceful period time length in seconds
      after time interval [starting time, starting time + duration].

   o Elastic-Lower-Bound: The maximum amount of time in seconds that
      time interval can shift to lower/left.

   o Elastic-Upper-Bound: The maximum amount of time in seconds that
      time interval can shift to upper/right.

4.4. Scheduled LSP Updates

   After a scheduled LSP is configured, a user may change its parameters
   including the requested time as well as the bandwidth.

   In PCC-Initiated case, the PCC can send a PCRpt message for the
   scheduled LSP with updated bandwidth as well as scheduled information
   included in the SCHED-LSP-ATTRIBUTE TLV (see section 4.3.4.1) or
   SCHED-PD-LSP-ATTRIBUTE TLV carried in the LSP Object. The PCE should
   calculate the updated resources and synchronized with other PCEs. If
   the updates can be satisfied, PCE shall return a PCUpd message to PCC
   as described in section 4.3.3. If the requested updates cannot be
   met, PCE shall return a PCUpd message with the original reserved
   attributes carried in the LSP Object.

   The stateful PCE can update the Scheduled LSP parameters to other
   PCEs and the requested PCC at any time based on any network events
   using the PCUpd message including SCHED-LSP-ATTRIBUTE TLV or SCHED-
   PD-LSP-ATTRIBUTE TLV in the LSP Object body.

4.5. Scheduled LSP activation and deletion

   In PCC-Initiated LSP scheduling, the PCC itself MAY activate the
   scheduled LSP at the starting time. Alternatively, the stateful PCE
   MAY activate the scheduled LSP at its scheduled time by send a
   PCInitiated message.

   After the scheduled duration expires, the PCE shall send a PCUpd
   message with R flag set to the PCC to delete the LSP over the path,
   as well as to other PCEs to remove the scheduled LSP in the
   databases. Additionally, it shall update its scheduled LSP DB and
   scheduled TED.

   Note that, the stateful PCE can update the Scheduled LSP parameters
   at any time based on any network events using the PCUpd message
   including SCHED-LSP-ATTRIBUTE TLV in the LSP Object body.

5. Security Considerations

   This document defines LSP-SCHEDULING-CAPABILITY TLV and SCHED- LSP-
   ATTRIBUTE TLV which does not add any new security concerns beyond
   those discussed in [RFC5440] and [I-D.ietf-pce-stateful-pce].

6. Manageability Consideration

6.1. Control of Function and Policy

   The LSP-Scheduling feature MUST BE controlled per tunnel by the
   active stateful PCE, the values for parameters like starting time,
   duration SHOULD BE configurable by customer applications and based on
   the local policy at PCE.

6.2. Information and Data Models

   [RFC7420] describes the PCEP MIB, there are no new MIB Objects for
   this document.

6.3. Liveness Detection and Monitoring

   Mechanisms defined in this document do not imply any new liveness
   detection and monitoring requirements in addition to those already
   listed in [RFC5440].

6.4. Verify Correct Operations

   Mechanisms defined in this document do not imply any new operation
   verification requirements in addition to those already listed in
   [RFC5440].

6.5. Requirements On Other Protocols

   Mechanisms defined in this document do not imply any new requirements
   on other protocols.

6.6. Impact On Network Operations

   Mechanisms defined in this document do not have any impact on network
   operations in addition to those already listed in [RFC5440].

7. IANA Considerations

7.1. PCEP TLV Type Indicators

   This document defines the following new PCEP TLV; IANA is requested
   to make the following allocations from this registry.

   Value   Meaning   Reference
    TBD   SCHED-LSP-ATTRIBUTE   This document
    TBD   SCHED-PD-LSP-ATTRIBUTE   This document

7.2. LSP-SCHEDULING-CAPABLITY

   This document requests that a registry is created to manage the Flags
   field in the STATEFUL-PCE-CAPABILITY TLV in the OPEN object. New
   values are to be assigned by Standards Action [RFC5226]. Each bit
   should be tracked with the following qualities:

   o Bit number (counting from bit 0 as the most significant bit)

   o Capability description

   o Defining RFC

   The following values are defined in this document:

   Bit   Description   Reference
    28   LSP-SCHEDULING-CAPABILITY (B-bit)   This document
    29   PD-LSP-CAPABLITY (PD-bit)   This document

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   Zhang for the review and comments.

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Appendix A. Scheduled LSP information synchronization

   As for a stateful PCE, it maintains a database of LSPs (LSP-DB) that
   are active in the network, so as to reveal the available network
   resources and place new LSPs more cleverly.

   With the scheduled LSPs, they are not activated while creation, but
   should be considered when operating future path computation. Hence,
   a scheduled LSP Database (SLSP-DB) is suggested to maintain all
   scheduled LSP information.

   The information of SLSP-DB MUST be shared and synchronized among all
   PCEs within the centralized network by using PCReq message, PCRep
   message with scheduled LSP information. In order to synchronize the
   scheduled LSP information in SLSP-DB among PCEs, the PCReq message
   and PCRep Message is used as described in section 4.3.1 and section
   4.3.2.

   To achieve the synchronization, the PCE should generate and maintain
   a scheduled TED based on LSP DB, scheduled LSP DB and TED, which is
   used to indicate the network resource availability on network nodes
   for LSP path computation.

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