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       PCE Communication Protocol (PCEP) Extensions for Label Switched Path
                    (LSP) Scheduling with Stateful PCE

Abstract

   This document defines a set of extensions to the stateful PCE
   Communication Protocol (PCEP) to enable Label Switched Path (LSP)
   path computation, activation, setup, and deletion based on scheduled
   time intervals for the LSP and the actual network resource usage in a
   centralized network environment, as stated in RFC 8413.

Status of This Memo

   This is an Internet Standards Track document.

   This document is a product of the Internet Engineering Task Force
   (IETF). It represents the consensus of the IETF community. It has
   received public review and has been approved for publication by the
   Internet Engineering Steering Group (IESG). Further information on
   Internet Standards is available in Section 2 of RFC 7841.

   Information about the current status of this document, any errata,
   and how to provide feedback on it may be obtained at
   https://www.rfc-editor.org/info/rfc8934.

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1. Introduction

   The PCE Communication Protocol (PCEP) defined in [RFC5440] is used
   between a Path Computation Element (PCE) and a Path Computation
   Client (PCC) (or other PCE) to enable path computation of
   Multiprotocol Label Switching (MPLS) Traffic Engineering Label
   Switched Paths (TE LSPs).

   [RFC8231] describes a set of extensions to PCEP to provide stateful
   control. A stateful PCE has access to not only the information
   carried by the network's Interior Gateway Protocol (IGP) but also the
   set of active paths and their reserved resources for its
   computations. The additional state allows the PCE to compute
   constrained paths while considering individual LSPs and their
   interactions.

   Traditionally, the usage and allocation of network resources,
   especially bandwidth, can be supported by a Network Management System
   (NMS) operation such as path pre-establishment. However, this does
   not provide efficient usage of network resources. The established
   paths reserve the resources forever, so they cannot be used by other
   services even when they are not used for transporting any service.
   [RFC8413] then provides a framework that describes and discusses the
   problem and defines an appropriate architecture for the scheduled
   reservation of TE resources.

   The scheduled reservation of TE resources allows network operators to
   reserve resources in advance according to the agreements with their
   customers and allows them to transmit data about scheduling, such as
   a specified start 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 is really being
   used while letting other services use the bandwidth when it is not
   being used by this service. The requirement of scheduled LSP
   provisioning is mentioned in [RFC8231] and [RFC7399]. Also, for
   deterministic networks [RFC8655], the scheduled LSP or temporal LSP
   can provide better network resource usage for guaranteed links. This
   idea can also be applied in segment routing [RFC8402] to schedule the
   network resources over the whole network in a centralized manner.

   With this in mind, this document defines a set of needed extensions

to PCEP used for stateful PCEs 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 start time and a duration. When the end of the
LSP life is reached, it is deleted to free up the resources for other
LSPs (scheduled or not).

2. Conventions Used in This Document

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
BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all
capitals, as shown here.

2.1. Terminology

The following terminology is reused from existing PCE documents.

*   Active Stateful PCE [RFC8051]

*   Delegation [RFC8051]

*   PCE-initiated LSP [RFC8281]

*   PCC [RFC5440]

*   PCE [RFC5440]

*   TE LSP [RFC5440]

*   TED (Traffic Engineering Database) [RFC5440]

*   LSP-DB (LSP State Database) [RFC8051]

In addition, this document defines the following terminologies.

Scheduled TE LSP (or Scheduled LSP for short): An LSP with
   scheduling attributes that carries traffic flow demand at a start
   time and lasts for a certain duration (or from a start time to an
   end time, where the end time is the start time plus the duration).
   A scheduled LSP is also called a "temporal LSP". The PCE operates
   path computation per LSP availability for the required time and
   duration.

Scheduled LSP-DB (SLSP-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 the TED and scheduled LSP-DB; it allows
   knowing, at any time, the expected amount of available resources
   (discounting the possibility of failures in the future).

Start time (Start-Time): This value indicates when the scheduled LSP
   is used and the corresponding LSP must be set up and active. At
   other times (i.e., before the start time or after the start time
   plus duration), the LSP can be inactive to include the possibility
   of the resources being used by other services.

Duration: This value indicates the length of time that the LSP
   carries a traffic flow and the corresponding LSP must be set up
   and active. At the end of the duration, the LSP is torn down and
   removed from the database.

3. Motivation and Objectives

A stateful PCE [RFC8231] can support better efficiency by using LSP
scheduling described in the use case of [RFC8051]. This requires the
PCE to maintain the scheduled LSPs and their associated resource
usage (e.g., bandwidth for packet-switched network) as well as have
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 [RFC8231] as well as discussions in [RFC8413], doing this as a part of PCEP in a centralized manner has obvious advantages.

This document provides a set of extensions to PCEP to enable LSP scheduling for LSP creation/deletion under the stateful control of a PCE and according to traffic service requests from customers, so as to improve the usage of network resources.

4. Procedures and Mechanisms

4.1. LSP Scheduling Overview

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 utilization efficiency.

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 [RFC8231], while the other is the scheduled LSP database (SLSP-DB). The SLSP-DB records scheduled LSPs and is used in conjunction with 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 is an implementation matter, and this document does not state any preference.

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 the future. The scheduled TED MUST be maintained by all PCEs within the network environment.

In the case of implementing PCC-initiated scheduled LSPs, when delegating a scheduled LSP, a PCC MUST include that LSP's scheduling parameters (see Section 5.2.1), including the start time and duration, using a Path Computation State Report (PCRpt) message. Since the LSP is not yet signaled, at the time of delegation, the LSP would be in down state. Upon receiving the delegation of the scheduled LSP, a stateful PCE MUST check whether the parameters are valid. If they are valid, it SHALL check the scheduled TED for the network resource availability on network nodes, compute a path for the LSP with the scheduling information, and update to the PCC as per the active stateful PCE techniques [RFC8231].

Note that the active stateful PCE can update to the PCC with the path for the scheduled LSP at any time. However, the PCC should not signal the LSP over the path after receiving these messages since the path is not active yet; the PCC signals the LSP at the start time.

In the case of multiple PCEs within a single domain, the PCE would need to synchronize their scheduling information with other PCEs within the domain. This could be achieved by proprietary database-synchronization techniques or via a possible PCEP extension (see [PCE-STATE-SYNC]). The technique used to synchronize an SLSP-DB is out of scope for this document. When the scheduling information is out of synchronization among some PCEs, some scheduled LSPs may not be set up successfully.

The scheduled LSP can also be initiated by a PCE itself. In the case of implementing a PCE-initiated scheduled LSP, the stateful PCE SHALL check the network resource availability for the traffic, compute a path for the scheduled LSP, and initiate a scheduled LSP at the PCC and synchronize the scheduled LSP to other PCEs. Note that the PCC could be notified immediately or at the start time of the scheduled LSP, based on the local policy. In the former case, the SCHED-LSP-ATTRIBUTE TLV (see Section 5.2.1) MUST be included in the message, whereas for the latter, the SCHED-LSP-ATTRIBUTE TLV SHOULD NOT be included. Either way, the synchronization to other PCEs MUST be done

when the scheduled LSP is created.

In both modes, for activation of scheduled LSPs, the PCC MUST
initiate the setup of the scheduled LSP at the start time.
Similarly, on the scheduled usage expiry, the PCC MUST initiate the
removal of the LSP based on the flag set in the SCHED-LSP-ATTRIBUTE
TLV.

4.2. Support of LSP Scheduling

4.2.1. LSP Scheduling

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

When an LSP is configured with arbitrary scheduling period [Ta, Tb],
a path satisfying the constraints for the LSP in the scheduling
period 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 is
also periodical LSP scheduling.

Periodical LSP scheduling means an LSP has multiple time intervals
and the LSP is set up to carry traffic in every time interval. It
has a scheduling period 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 of a week" (representing 11
scheduling intervals), a path satisfying the constraints for the LSP
in every interval represented by the periodical scheduling interval
is computed once. Note that the path computed for one recurrence may
be different from the path for another recurrence. And then the LSP
along the path is set up to carry traffic in each of the scheduling
intervals. If there is no path satisfying the constraints for some
of the intervals, the LSP MUST NOT be set up at all. It MUST
generate a PCEP Error (PCErr) with Error-Type = 29 (Path computation
failure) and Error-value = 5 (Constraints could not be met for some
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 are amounts of time such as 300
seconds. P is called the elastic range lower bound, and Q is called
the 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
are shifted by the same X. This elastic time interval is suitable
for the case where a user wants to have a scheduled LSP up to carry
the traffic in time interval [Ta, Tb] and has some flexibility on
shifting the time interval a little bit, such as up to P seconds
earlier/left or some time such as up to Q seconds later/right.

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+Xv) to (Tb+Xv),
and an optimization is performed on Xv from -P to Q. The
optimization makes [Ta+Xv, Tb+Xv] 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+Xv) to
(Tb+Xv).

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. Grace Periods

Besides the stated time scheduling, a user may want to have some
grace periods (short for "graceful time periods") for each or some of
the time intervals for the LSP. Two grace periods may be configured
for a time interval. One is the grace period before the time
interval, called "Grace-Before", which extends the lifetime of the
LSP by an amount of time (such as 30 seconds) before the time
interval. The other grace period is after the time interval and is
called "Grace-After"; it extends the lifetime of the LSP by an amount
of time (such as 60 seconds) after the time interval. Note that no
network resources such as link bandwidth will be reserved for the LSP
during the grace periods.

When an LSP is configured with a simple time interval such as [Ta,
Tb] with grace periods such as Grace-Before GrB and Grace-After GrA,
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-GrB) to (Tb+GrA).
During grace periods from (Ta-GrB) to Ta and from Tb to (Tb+GrA), the
LSP is up to carry traffic in best effort.

4.3. Scheduled LSP Creation

In order to realize PCC-initiated scheduled LSPs in a centralized
network environment, a PCC MUST separate the setup of an LSP into two
steps. The first step is to request/delegate and get an LSP but not
signal it over the network. The second step is to signal the
scheduled LSP over the Label Switching Routers (LSRs) at its start
time.

For PCC-initiated scheduled LSPs, a PCC MUST delegate the scheduled
LSP by sending a PCRpt message by including its demanded resources
with the scheduling information to a stateful PCE. Note that the PCC
MAY use Path Computation Request (PCReq) and Path Computation Reply
(PCRep) messages with scheduling information before delegating.

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

The stateful PCE will send a Path Computation Update Request (PCUpd)
message with the scheduled path information and the scheduled
resource information for the scheduled LSP to the PCC. The stateful
PCE MUST update its local scheduled LSP-DB and scheduled TED with the
scheduled LSP and would need to synchronize the scheduling
information with other PCEs in the domain.

For a PCE-initiated scheduled LSP, the stateful PCE MUST
automatically compute a path for the scheduled LSP per requests from

network management systems, based on the network resource
availability in the scheduled TED, and send an LSP Initiate Request
(PCInitiate) message with the path information to the PCC. Based on
the local policy, the PCInitiate message could be sent immediately to
ask the PCC to create a scheduled LSP (as per this document), or the
PCInitiate message could be sent at the start time to the PCC to
create a normal LSP (as per [RFC8281]).

For both PCC-initiated and PCE-initiated Scheduled LSPs:

* The stateful PCE MUST update its local scheduled LSP-DB and
   scheduled TED with the scheduled LSP.

* Upon receiving the PCUpd message or PCInitiate message for the
   scheduled LSP from PCEs with a found path, the PCC determines that
   it is a scheduled path for the LSP by the SCHED-LSP-ATTRIBUTE TLV
   (see Section 5.2.1) or SCHED-PD-LSP-ATTRIBUTE TLV (see
   Section 5.2.2) in the message and does not trigger signaling for
   the LSP setup on LSRs immediately.

* The stateful PCE MUST update the scheduled LSP parameters on any
   network events using the PCUpd message to the PCC. These changes
   are also synchronized to other PCEs.

* When it is time for the LSP to be set up (i.e., at the start
   time), based on the value of the C flag for the scheduled TLV,
   either the PCC MUST trigger the LSP to be signaled or the
   delegated PCE MUST send a PCUpd message to the head-end LSR
   providing the updated path to be signaled (with the A flag set to
   indicate LSP activation).

4.4. Scheduled LSP Modifications

   After a scheduled LSP is configured, a user may change its
   parameters, including the requested time and the bandwidth. For a
   periodic-scheduled LSP, its unused recurrences can be modified or
   canceled. For a scheduled LSP that is currently active, its duration
   (the lifetime) can be reduced.

   In the PCC-initiated case, the PCC MUST send the PCE a PCRpt message
   for the scheduled LSP with updated parameters, as well as scheduled
   information included in the SCHED-LSP-ATTRIBUTE TLV (see
   Section 5.2.1) or SCHED-PD-LSP-ATTRIBUTE TLV (see Section 5.2.2)
   carried in the LSP object. The PCE SHOULD take the updated resources
   and schedule into consideration, and update the new path for the
   scheduled LSP to the PCC, and synchronize to other PCEs in the
   network. If the path cannot be set based on new requirements, the
   previous LSP will not be impacted, and this MUST be conveyed by the
   use of an empty Explicit Route Object (ERO) in the PCEP messages.

   In the PCE-initiated case, the stateful PCE would recompute the path
   based on updated parameters and scheduled information. If it has
   already conveyed this information to the PCC by sending a PCInitiate
   message, it SHOULD update the path and other scheduling and resource
   information by sending a PCUpd message.

4.5. Scheduled LSP Activation and Deletion

   In the PCC-initiated case, when it is time for the LSP to be set up
   (i.e., at the start time), based on the value of the C flag for the
   scheduled TLV, either the PCC MUST trigger the LSP to be signaled, or
   the delegated PCE MUST send a PCUpd message to the head-end LSR
   providing the updated path to be signaled (with the A flag set to
   indicate LSP activation). The PCC MUST report the status of the
   active LSP as per the procedures in [RFC8231], and at this time, the
   LSP MUST be considered part of the LSP-DB. The A flag MUST be set in
   the scheduled TLV to indicate that the LSP is active now. After the
   scheduled duration expires, based on the C flag, the PCC MUST trigger
   the LSP deletion on itself, or the delegated PCE MUST send a PCUpd
   message to the PCC to delete the LSP as per the procedures in
   [RFC8231].

In the PCE-initiated case, based on the local policy, if the
scheduled LSP is already conveyed to the PCC at the time of creation,
the handling of LSP activation and deletion is handled in the same
way as the PCC-initiated case, as per the setting of the C flag.
Otherwise, the PCE MUST send the PCInitiate message to the PCC at the
start time to create a normal LSP without the scheduled TLV and
remove the LSP after the duration expires, as per [RFC8281].

5. PCEP Objects and TLVs

5.1. Stateful PCE Capability TLV

A PCC and a PCE indicate their ability to support LSP scheduling
during their PCEP session establishment phase. For an environment
with multiple PCEs, the PCEs SHOULD also establish a 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. Note that the STATEFUL-PCE-CAPABILITY TLV is defined in
[RFC8231] and updated in [RFC8281] and [RFC8232]. In this document,
we define a new flag bit B (LSP-SCHEDULING-CAPABILITY) in the Flags
field of the STATEFUL-PCE-CAPABILITY TLV to indicate the support of
LSP scheduling. We also define another flag bit PD (PD-LSP-
CAPABILITY) to indicate the support of LSP periodical scheduling.

   B (LSP-SCHEDULING-CAPABILITY) - 1 bit (Bit Position 22): 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-CAPABILITY) - 1 bit (Bit Position - 21): 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. Both the PD bit and
      the B bit MUST be set to 1 by both PCEP peers in order to support
      periodical LSP scheduling for path computation. If the PD bit or
      B bit is 0, then the periodical LSP scheduling capability MUST be
      ignored.

5.2. LSP Object

The LSP object is defined in [RFC8231]. This document adds an
optional SCHED-LSP-ATTRIBUTE TLV for normal LSP scheduling and an
optional SCHED-PD-LSP-ATTRIBUTE TLV for periodical LSP scheduling.
The LSP object for a scheduled LSP MUST NOT include these two TLVs.
Only one scheduling, either normal or periodical, is allowed for a
scheduled LSP.

The presence of the SCHED-LSP-ATTRIBUTE TLV in the LSP object
indicates that this LSP is normal scheduling while the SCHED-PD-LSP-
ATTRIBUTE TLV indicates that this scheduled LSP is periodical. The
SCHED-LSP-ATTRIBUTE TLV MUST be present in the LSP object for each
normal-scheduled LSP carried in the PCEP messages. The SCHED-PD-LSP-
ATTRIBUTE TLV MUST be used in the LSP object for each periodic-
scheduled LSP carried in the PCEP messages.

Only one SCHED-LSP-ATTRIBUTE TLV SHOULD be present in the LSP object.
If more than one SCHED-LSP-ATTRIBUTE TLV is found, the first instance
is processed and others ignored. The SCHED-PD-LSP-ATTRIBUTE TLV is
the same as the SCHED-LSP-ATTRIBUTE TLV with regard to its presence
in the LSP object.

5.2.1. SCHED-LSP-ATTRIBUTE TLV

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

This TLV MUST NOT be included unless both PCEP peers have set the B
(LSP-SCHEDULING-CAPABILITY) bit in the STATEFUL-PCE-CAPABILITY TLV
carried in the Open message to one. If the TLV is received by a peer

when both peers didn't set the B bit to one, the peer MUST generate a
PCEP Error (PCErr) with a PCEP-ERROR object having Error-Type = 19
(Invalid Operation) and Error-value = 15 (Attempted LSP scheduling
while the scheduling capability was not advertised).

The format of the SCHED-LSP-ATTRIBUTE TLV is shown in Figure 1.

```
 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 (49)           |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Flags |R|C|A|G|                 Reserved (0)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Start-Time                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Duration                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   GrB / Elastic-Lower-Bound   |   GrA / Elastic-Upper-Bound   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
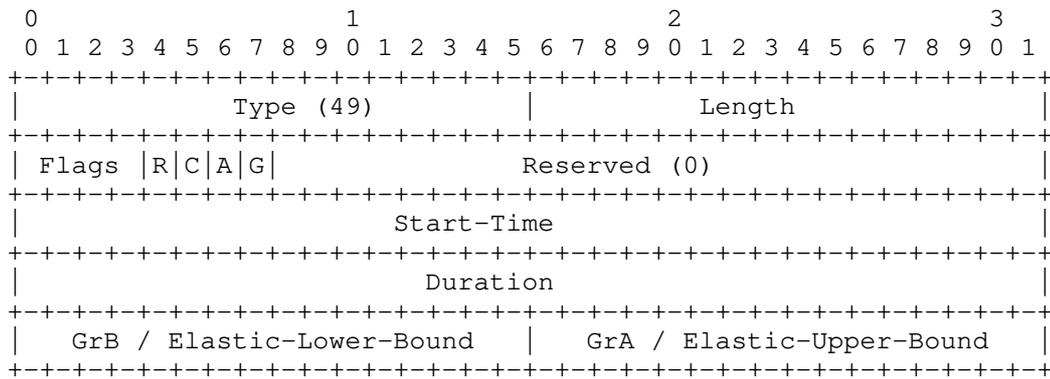
Figure 1: SCHED-LSP-ATTRIBUTE TLV

The type of the TLV is 49, and the TLV has a fixed length of 16
octets.

The fields in the format are:

Flags (8 bits): The following flags are defined in this document.

   R (1 bit): Set to 1 to indicate that the Start-Time is a relative
      time, which is the number of seconds from the current time.
      The PCEs and PCCs MUST synchronize their clocks when relative
      time is used. It is RECOMMENDED that the Network Time Protocol
      [RFC5905] be used to synchronize clocks among them. When the
      transmission delay from a PCE or PCC to another PCE or PCC is
      too big (such as greater than 1 second), the scheduling
      interval represented is not accurate if the delay is not
      considered. Set to 0 to indicate that the 32-bit Start-Time is
      an absolute time, which is the number of seconds since the
      epoch. The epoch is 1 January 1970 at 00:00 UTC. It wraps
      around every 2^32 seconds, which is roughly 136 years. The
      next wraparound will occur in the year 2106. The received
      Start-Time is considered after the wraparound if the resulting
      value is less than the current time. In that case, the value
      of the 32-bit Start-Time is considered to be the number of
      seconds from the time of wraparound (because the Start-Time is
      always a future time).

   C (1 bit): Set to 1 to indicate that the PCC is responsible to
      set up and remove the scheduled LSP based on the Start-Time and
      Duration. The PCE holds these responsibilities when the bit is
      set to zero.

   A (1 bit): Set to 1 to indicate that the scheduled LSP has been
      activated.

   G (1 bit): Set to 1 to indicate that the grace period is included
      in the fields GrB/Elastic-Lower-Bound and GrA/Elastic-Upper-
      Bound; set to 0 to indicate that the elastic range is included
      in the fields.

Reserved (24 bits): This field MUST be set to zero on transmission
   and MUST be ignored on receipt.

Start-Time (32 bits): This value, in seconds, indicates when the

scheduled LSP is used to carry traffic and the corresponding LSP
MUST be set up and activated. Note that the transmission delay
SHOULD be considered when R=1 and the value of Start-Time is
small.

Duration (32 bits): This value, in seconds, indicates the duration
that the LSP carries a traffic flow and the corresponding LSP MUST
be up to carry traffic. At the expiry of this duration, the LSP
MUST be torn down and deleted. A value of 0 MUST NOT be used in
Duration since it does not make any sense. The value of Duration
SHOULD be greater than a constant MINIMUM-DURATION seconds, where
MINIMUM-DURATION is 5.

Start-Time indicates a time at or before which the scheduled LSP MUST
be set up. When the R bit is set to 0, the value of Start-Time
represents the number of seconds since the epoch. When the R bit is
set to 1, the value of Start-Time represents the number of seconds
from the current time.

In addition, the SCHED-LSP-ATTRIBUTE TLV contains the G flag set to 1
and a nonzero Grace-Before and Grace-After in the fields GrB/Elastic-
Lower-Bound and GrA/Elastic-Upper-Bound if grace periods are
configured. It includes the G flag set to 0 and a nonzero elastic
range lower bound and upper bound in the fields if there is an
elastic range configured. A TLV can configure a nonzero grace period
or elastic range, but it MUST NOT provide both for an LSP.

GrB (Grace-Before, 16 bits): The grace period time length, in
seconds, before the start time.

GrA (Grace-After, 16 bits): The grace period time length, in
seconds, after time interval [start time, start time + duration].

Elastic-Lower-Bound (16 bits): The maximum amount of time, in
seconds, that the time interval can shift lower/left.

Elastic-Upper-Bound (16 bits): The maximum amount of time, in
seconds, that the time interval can shift higher/right.

5.2.2. 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 MUST NOT be included unless both PCEP peers have set the B
(LSP-SCHEDULING-CAPABILITY) bit and PD (PD-LSP-CAPABILITY) bit in
STATEFUL-PCE-CAPABILITY TLV carried in Open message to one. If the
TLV is received by a peer when either bit is zero (or both bits are
zero), the peer MUST generate a PCEP Error (PCErr) with a PCEP-ERROR
object having Error-Type = 19 (Invalid Operation) and Error-value =
15 (Attempted LSP scheduling while the scheduling capability was not
advertised).

The format of the SCHED-PD-LSP-ATTRIBUTE TLV is shown in Figure 2.

```
 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 (50)           |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Flags|R|C|A|G| Opt   |             NR            | Reserved (0) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Start-Time                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Duration                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
|                      Repeat-time-length                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   GrB / Elastic-Lower-Bound   |  GrA / Elastic-Upper-Bound    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
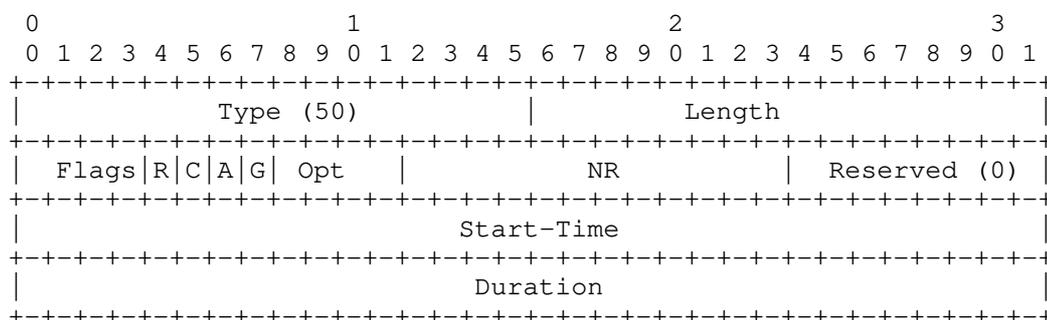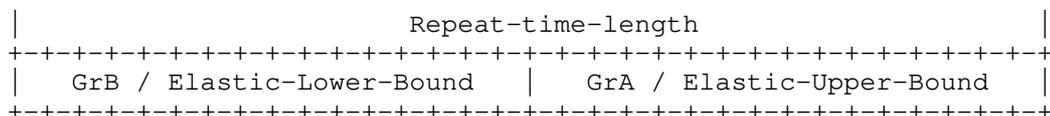
                   Figure 2: SCHED-PD-LSP-ATTRIBUTE TLV

   The type of the TLV is 50, and the TLV has a fixed length of 20
   octets. The description, format, and meaning of the flags (R, C, A,
   and G bits), Start-Time, Duration, GrB, GrA, Elastic-Lower-Bound, and
   Elastic-Upper-Bound fields remain the same as in the SCHED-LSP-
   ATTRIBUTE TLV.

   The following fields are new:

   Opt (4 bits): Indicates options to repeat. When a PCE receives a
      TLV with an unknown Opt value, it does not compute any path for
      the LSP. It MUST generate a PCEP Error (PCErr) with a PCEP-ERROR
      object having Error-Type = 4 (Not supported object) and Error-
      value = 4 (Unsupported parameter).

         Opt = 1: repeat every month

         Opt = 2: repeat every year

         Opt = 3: repeat every Repeat-time-length

      A user may configure a Repeat-time-length in time units weeks,
      days, hours, minutes, and/or seconds. The value represented by
      these units is converted to the number of seconds in the TLV. For
      example, repeat every 2 weeks is equivalent to repeat every
      Repeat-time-length = 2*7*86,400 (seconds), where 86,400 is the
      number of seconds per day.

   NR (12 bits): The number of repeats. During each repetition, LSP
      carries traffic.

   Reserved (8 bits): This field MUST be set to zero on transmission
      and MUST be ignored on receipt.

   Repeat-time-length (32 bits): The time in seconds between the Start-
      Time of one repetition and the Start-Time of the next repetition.

6. The PCEP Messages

6.1. The PCRpt Message

   The Path Computation State Report (PCRpt) message is a PCEP message
   sent by a PCC to a PCE to report the status of one or more LSPs, as
   per [RFC8231]. Each LSP State Report in a PCRpt message contains the
   actual LSP's path, bandwidth, operational and administrative status,
   etc. An LSP Status Report carried in a PCRpt message is also used in
   delegation or revocation of control of an LSP to/from a PCE. In the
   case of a scheduled LSP, a scheduled TLV MUST be carried in the LSP
   object, and the ERO conveys the intended path for the scheduled LSP.
   The scheduled LSP MUST be delegated to a PCE.

6.2. The PCUpd Message

   The Path Computation Update Request (PCUpd) message is a PCEP message
   sent by a PCE to a PCC to update LSP parameters on one or more LSPs,
   as per [RFC8231]. Each LSP Update Request in a PCUpd message
   contains all LSP parameters that a PCE wishes to be set for a given
   LSP. In the case of a scheduled LSP, a scheduled TLV MUST be carried
   in the LSP object, and the ERO conveys the intended path for the
   scheduled LSP. If no path can be found, an empty ERO is used. The A
   bit is used in the PCUpd message to indicate the activation of the
   scheduled LSP if the PCE is responsible for the activation (as per
   the C bit).

6.3. The PCInitiate Message

The LSP Initiate Request (PCInitiate) message is a PCEP message sent
by a PCE to a PCC to trigger LSP instantiation or deletion, as per
[RFC8281]. In the case of a scheduled LSP, based on the local
policy, the PCE MAY convey the scheduled LSP to the PCC by including
a scheduled TLV in the LSP object. Alternatively, the PCE would
initiate the LSP only at the start time of the scheduled LSP, as per
[RFC8281], without the use of scheduled TLVs.

6.4. The PCReq message

The Path Computation Request (PCReq) message is a PCEP message sent
by a PCC to a PCE to request a path computation [RFC5440], and it may
contain the LSP object [RFC8231] to identify the LSP for which the
path computation is requested. In the case of a scheduled LSP, a
scheduled TLV MUST be carried in the LSP object in the PCReq message
to request the path computation based on the scheduled TED and LSP-
DB. A PCC MAY use the PCReq message to obtain the scheduled path
before delegating the LSP. The parameters of the LSP may be changed
(refer to Section 4.4).

6.5. The PCRep Message

The Path Computation Reply (PCRep) message is a PCEP message sent by
a PCE to a PCC in reply to a path computation request [RFC5440], and
it may contain the LSP object [RFC8231] to identify the LSP for which
the path is computed. A PCRep message can contain either a set of
computed paths if the request can be satisfied or a negative reply if
not. A negative reply may indicate the reason why no path could be
found. In the case of a scheduled LSP, a scheduled TLV MUST be
carried in the LSP object in PCRep message to indicate the path
computation based on the scheduled TED and LSP-DB. A PCC and PCE MAY
use PCReq and PCRep messages to obtain the scheduled path before
delegating the LSP.

6.6. The PCErr Message

The PCEP Error (PCErr) message is a PCEP message, as described in
[RFC5440], for error reporting. This document defines new error
values for several error types to cover failures specific to
scheduling and reuses the applicable error types and error values of
[RFC5440] and [RFC8231] wherever appropriate.

The PCEP extensions for scheduling MUST NOT be used if one or both of
the PCEP speakers have not set the corresponding bits in the
STATEFUL-PCE-CAPABILITY TLV in their respective Open messages to one.
If the PCEP speaker supports the extensions of this specification but
did not advertise this capability, then upon receipt of LSP object
with the scheduled TLV, it MUST generate a PCEP Error (PCErr) with
Error-Type = 19 (Invalid Operation) and Error-value = 15 (Attempted
LSP scheduling while the scheduling capability was not advertised),
and it SHOULD ignore the TLV. As per Section 7.1 of [RFC5440], a
legacy PCEP implementation that does not understand this
specification would consider a scheduled TLV unknown and ignore it.

If the PCC decides that the scheduling parameters proposed in the
PCUpd/PCInitiate message are unacceptable, it MUST report this error
by including the LSP-ERROR-CODE TLV (Section 7.3.3 of [RFC8231]) with
LSP Error-value = 4 (Unacceptable parameters) in the LSP object (with
the scheduled TLV) in the PCRpt message to the PCE.

The scheduled TLV MUST be included in the LSP object for the
scheduled LSPs. If the TLV is missing, the receiving PCEP speaker
MUST send a PCErr message with Error-Type = 6 (Mandatory Object
missing) and Error-value = 16 (Scheduled TLV missing).

7. Security Considerations

This document defines the LSP-SCHEDULING-CAPABILITY TLV and SCHED-
LSP-ATTRIBUTE TLV; the security considerations discussed in
[RFC5440], [RFC8231], and [RFC8281] continue to apply. In some

deployments, the scheduling information could provide details about
the network operations that could be deemed extra sensitive.
Additionally, snooping of PCEP messages with such data or using PCEP
messages for network reconnaissance may give an attacker sensitive
information about the operations of the network. A single PCEP
message can now instruct a PCC to set up and tear down an LSP every
second for a number of times. That single message could have a
significant effect on the network. Thus, such deployments SHOULD
employ suitable PCEP security mechanisms like TCP Authentication
Option (TCP-AO), which is discussed in [RFC5925] and [RFC8253]. Note
that [RFC8253] is considered a security enhancement and thus is much
better suited for sensitive information. PCCs may also need to apply
some form of rate limit to the processing of scheduled LSPs.

8. Manageability Consideration

8.1. Control of Function and Policy

The LSP scheduling feature MUST be controlled per tunnel by the
active stateful PCE. The values for parameters like start time and
duration SHOULD be configurable by customer applications and based on
the local policy at PCE. The suggested default values for start time
and duration are one day (in seconds) from the current time and one
year (in seconds), respectively. One day has 86,400 seconds. One
year has 31,536,000 seconds.

When configuring the parameters for time, a user SHOULD consider leap
years and leap seconds. If a scheduled LSP has a time interval
containing a leap year, the duration of the LSP is 366 days plus the
rest of the interval.

8.2. Information and Data Models

An implementation SHOULD allow the operator to view the information
about each scheduled LSP defined in this document. To serve this
purpose, the PCEP YANG module [PCE-PCEP-YANG] could be extended.

8.3. 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].

8.4. Verify Correct Operations

Mechanisms defined in this document do not imply any new operation
verification requirements in addition to those already listed in
[RFC5440]. An implementation SHOULD allow a user to view
information, including the status of a scheduled LSP, through a
Command Line Interface (CLI) tool. In addition, it SHOULD check and
handle the cases where there is a significant time correction or a
clock skew between PCC and PCE.

8.5. Requirements on Other Protocols

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

8.6. 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].

9. IANA Considerations

9.1. PCEP TLV Type Indicators

IANA maintains the "PCEP TLV Type Indicators" subregistry within the
"Path Computation Element Protocol (PCEP) Numbers" registry. IANA
has made the following allocations in this subregistry for the new
PCEP TLVs defined in this document.

Value	Description	Reference
49	SCHED-LSP-ATTRIBUTE	This document
50	SCHED-PD-LSP-ATTRIBUTE	This document

Table 1: Additions to PCEP TLV Type Indicators
Subregistry

9.1.1. SCHED-PD-LSP-ATTRIBUTE TLV Opt Field

IANA has created and will maintain a new subregistry named "SCHED-PD-LSP-ATTRIBUTE TLV Opt Field" within the "Path Computation Element Protocol (PCEP) Numbers" registry. Initial values for the subregistry are given below. New values are assigned by Standards Action [RFC8126].

Value	Description	Reference
0	Reserved	
1	REPEAT-EVERY-MONTH	This document
2	REPEAT-EVERY-YEAR	This document
3	REPEAT-EVERY-REPEAT-TIME-LENGTH	This document
4-14	Unassigned	
15	Reserved	

Table 2: New SCHED-PD-LSP-ATTRIBUTE TLV Opt Field
Subregistry

9.1.2. Schedule TLVs Flag Field

IANA has created a new subregistry named "Schedule TLVs Flag Field" within the "Path Computation Element Protocol (PCEP) Numbers" registry. New values are assigned by Standards Action [RFC8126]. Each bit should be tracked with the following qualities:

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

*   Capability description

*   Defining RFC

The following values are defined in this document:

Bit	Description	Reference
0-3	Unassigned	
4	Relative Time (R-bit)	This document
5	PCC Responsible (C-bit)	This document
6	LSP Activated (A-bit)	This document
7	Grace Period Included (G-bit)	This document

Table 3: New Schedule TLVs Flag Field Subregistry

9.2. STATEFUL-PCE-CAPABILITY TLV Flag Field

This document defines new bits in the Flags field in the STATEFUL-
PCE-CAPABILITY TLV in the OPEN object. IANA maintains the "STATEFUL-
PCE-CAPABILITY TLV Flag Field" subregistry within the "Path
Computation Element Protocol (PCEP) Numbers" registry. IANA has made
the following allocations in this subregistry.

Bit	Description	Reference
22	LSP-SCHEDULING-CAPABILITY (B-bit)	This document
21	PD-LSP-CAPABILITY (PD-bit)	This document

Table 4: Additions to STATEFUL-PCE-CAPABILITY TLV Flag
Field Subregistry

9.3. PCEP-ERROR Object Error Types and Values

IANA has allocated the following new error types to the existing
error values within the "PCEP-ERROR Object Error Types and Values"
subregistry of the "Path Computation Element Protocol (PCEP) Numbers"
registry:

Error-Type	Meaning	Error-value
6	Mandatory Object missing	16: Scheduled TLV missing
19	Invalid Operation	15: Attempted LSP scheduling while the scheduling capability was not advertised
29	Path computation failure	5: Constraints could not be met for some intervals

Table 5: Additions to PCEP-ERROR Object Error Types and
Values Subregistry

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