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PCEP Extensions for LSP scheduling with stateful PCE
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Abstract

This document defines 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 and the duration of a traffic service in a centralized network environment as stated in RFC 8413.

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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 path computation of Multi-protocol 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 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. [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 really being used while letting other services use it when this service is not using it. The requirement of scheduled LSP provision is mentioned in [RFC8231] and [RFC7399], so as to provide more efficient network resource usage for traffic engineering, which hasn't been solved yet. Also, for deterministic networks [I-D.ietf-detnet-architecture], the scheduled LSP or temporal LSP can provide a 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 as well.

With this in mind, this document defines a set of extensions needed 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 starting 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 terminologies are re-used from existing PCE documents.

- Active Stateful PCE [RFC8231];
- Passive Stateful PCE [RFC8231];
- Delegation [RFC8231];
- PCE-Initiated LSP [RFC8281];
- PCC [RFC5440], [RFC8231];
- PCE [RFC5440], [RFC8231];
- TE LSP [RFC5440], [RFC8231];
- TED [RFC5440], [RFC8231];
- LSP-DB [RFC8231];

In addition, this document defines the following terminologies.

Scheduled TE LSP (or Scheduled LSP for short): an LSP with the scheduling attributes, that carries traffic flow demand at a starting time and lasts for a certain duration (or from a starting time to an ending time, where the ending time is the starting 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: 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: This 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 torn down and removed from the data base.

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

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 [RFC8231], while the other is the scheduled LSP database (SLSP-DB, see section 6). 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 future. The scheduled TED should be maintained by all PCEs within the network environment.

In case of implementing PCC-initiated scheduled LSPs, before a PCC delegates a scheduled LSP, it MAY use the PCReq/PCRep messages to learn the path for the scheduled LSP. A PCC MUST delegate a scheduled LSP with information of its scheduling parameters, including the starting time and the duration using 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 SHALL check the scheduled TED for the network resource availability on network nodes and computes 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 on receiving these messages since the path is not active yet; PCC signals the LSP at the starting time.

For a multiple PCE environment, a PCE MUST synchronize to other PCEs within the network, so as to keep their scheduling information synchronized. There are many ways that this could be achieved: one such mechanism is described in [I-D.litkowski-pce-state-sync]. Which way is used to achieve this is out of scope for this document. The scheduled TED can be determined from the synchronized SLSP-DB. The PCE with delegation for the scheduled LSP would report the scheduled LSP to other PCEs, any future update to the scheduled LSP is also updated to other PCEs. This way the state of all scheduled LSPs are synchronized among the PCEs. [RFC7399] discusses some synchronization issues and considerations, that are also applicable to the scheduled databases.

The scheduled LSP 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 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 starting time of the

scheduled LSP based on the local policy. In case of former SCHED-LSP-ATTRIBUTE TLV (see Section 5.2.1) MUST be included in the message where as for the latter SCHED-LSP-ATTRIBUTE TLV SHOULD NOT be included. Either way the synchronization to other PCEs should be done when the scheduled LSP is created.

In both modes, for activation of scheduled LSPs, the PCC could initiate the setup of scheduled LSP at the start time by itself or wait for the PCE to update the PCC to initiate the setup of LSP. Similarly on the scheduling usage expires, the PCC could initiate the removal by itself or wait for the PCE to request the removal of the LSP. This is based on the Flag set in 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 duration from 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 is shifted by 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, [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. 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 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 grace 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 grace periods from (Ta-GB) to Ta and from Tb to (Tb+GA), the LSP is up to carry traffic (maybe in best effort).

4.3. Scheduled LSP creation

In order to realize PCC-Initiated scheduled LSPs in a centralized network environment, a PCC has to 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 LSRs (Label Switching Router) at its starting time.

For PCC-Initiated scheduled LSPs, a PCC can delegate the scheduled LSP by sending a path computation report (PCRpt) message by including its demanded resources with the scheduling information to a stateful PCE. Note the PCC MAY use the PCReq/PCRep with scheduling information before delegating.

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).

The stateful PCE will send a PCUpd message with the scheduled path information as well as the scheduled resource information for the scheduled LSP to the PCC. The PCE SHOULD add the scheduled LSP into its scheduled LSP-DB and update its scheduled TED.

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, send a PCInitiate message with the path information back to the PCC. Based on the local policy, the PCInitiate message could be sent immediately to ask 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]).

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 PCRpt message with the scheduled LSP to other PCEs within the

network, so as to achieve the scheduling traffic engineering information synchronization.

- Upon receiving the PCUpd message or PCInitiate message for the scheduled LSP from PCEs with a found path, the PCC knows that it is a scheduled path for the LSP and does not trigger signaling for the LSP setup on LSRs immediately.

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

- Based on the configuration (and the C flag in scheduled TLVs), when it is time (i.e., at the start time) for the LSP to be set up, either the PCC triggers the LSP to be signaled or the delegated PCE sends a PCUpd message to the head end LSR providing the updated path to be signaled (with 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 as well as the bandwidth.

In PCC-Initiated case, the PCC can send 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 would take the updated resources and schedule into considerations and update the new path for the scheduled LSP to the PCC as well as synchronize to other PCEs in the network. In case path cannot be set based on new requirements the same should be conveyed by the use of empty ERO in the PCEP messages.

In PCE-Initiated case, the Stateful PCE would recompute the path based on updated parameters as well as scheduled information. In case it has already conveyed to the PCC this information 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 PCC-Initiated case, based on the configuration (and the C flag in scheduled TLVs), when it is time (i.e., at the start time) for the LSP to be set up, either the PCC triggers the LSP to be signaled or the delegated PCE sends a PCUpd message to the head end LSR providing the updated path to be signaled (with A flag set to indicate LSP activation). The PCC would report the status of the active LSP as

per the procedures in [RFC8231] and at this time the LSP MUST be considered as part of the LSP-DB. The A flag MUST be set in the scheduled TLVs to indicate that the LSP is active now. After the scheduled duration expires, based on the C flag, the PCC triggers the LSP deletion on itself or the delegated PCE sends a PCUpd message to the PCC to delete the LSP as per the procedures in [RFC8231].

In 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 PCC-Initiated case as per the setting of C flag. In other case, the PCE would send the PCInitiate message at the start time to the PCC to create a normal LSP without the scheduled TLVs and remove the LSP after the duration expires as per [RFC8281].

5. PCEP Objects and TLVs

5.1. 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 [RFC8231]. 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 (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) [Bit Position - TBD3]: 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): [Bit Position - TBD4] 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.

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 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 PCEP messages. For periodical LSPs, the SCHED-PD-LSP-ATTRIBUTE TLV can be used in LSP Object for each periodic scheduled LSP carried in the PCEP messages.

Only one of these TLV SHOULD be present in the LSP object. In case more than one scheduling TLV is found, the first instance is processed and others ignored.

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 SHOULD NOT be included unless both PCEP peers have set the B (LSP-SCHEDULING-CAPABILITY bit) in STATEFUL-PCE-CAPABILITY TLV carried in the Open message.

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 (TBD1)       |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Flags |R|C|A|               Reserved (0)                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Start-Time                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Duration                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                GrB            |             GrA               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Elastic-Lower-Bound      |      Elastic-Upper-Bound      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: SCHED-LSP-ATTRIBUTE TLV

The type of the TLV is [TBD1] and the TLV has a fixed length of 20 octets.

The fields in the format are:

Flags (8 bits): Following flags are defined in this document

R (1 bit): Set to 1 to indicate the Start-Time is a relative time, which is relative to the current time; 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. After the wraparound, the value of the 32-bit Start-Time is the number of seconds from the time of wraparound because the Start-Time is always a future time. Just before the wraparound, if the time at which the LSP is to be activated is after the wraparound, the time is represented by the number of seconds from the time of wraparound in the 32-bit Start-Time.

C (1 bit): Set to 1 to indicate the PCC is responsible to setup and remove the scheduled LSP based on the Start-Time and duration.

A (1 bit): Set to 1 to indicate the scheduled LSP has been activated and should be considered as part of LSP-DB (instead of Scheduled LSP-DB).

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 setup and activated.

Duration (32 bits): The value in seconds, 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 torn down and deleted.

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

In addition, it contains an non zero grace-before and grace-after if grace 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 -16 bits): The grace period time length in seconds before the starting time.

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

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

o Elastic-Upper-Bound (16 bits): The maximum amount of time in seconds that time interval can shift to upper/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 SHOULD NOT be included unless 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 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 (TBD2)        |         Length                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Flags  |R|C|A| Opt   |           NR          |  Reserved (0) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Start-Time                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Duration                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Repeat-time-length                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                GrB            |             GrA               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Elastic-Lower-Bound      |      Elastic-Upper-Bound      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: SCHED-PD-LSP-ATTRIBUTE TLV

The type of the TLV is [TBD2] and the TLV has a fixed length of 24 octets. The description, format and meaning of the Flags (R, C and A bit), Start-Time, Duration, GrB, GrA, Elastic-Lower-Bound and Elastic-Upper-Bound fields remains same as SCHED-LSP-ATTRIBUTE TLV.

The following fields are new :

Opt: (4 bits) Indicates options 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.

NR: (12 bits) The number of repeats. In each of repeats, 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 length in seconds after which LSP starts to carry traffic again for the Duration.

6. The PCEP Messages

6.1. The PCRpt Message

Path Computation State Report (PCRpt) 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 on a PCRpt message is also used in delegation or revocation of control of an LSP to/from a PCE. In case of scheduled LSP, the scheduled TLVs 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. This message is also used to synchronize the scheduled LSPs to other PCE as described in [RFC8231]

6.2. The PCUpd Message

Path Computation Update Request (PCUpd) 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 on a PCUpd message contains all LSP parameters that a PCE wishes to be set for a given LSP. In case of scheduled LSP, the scheduled TLVs MUST be carried in the LSP object and the ERO conveys the intended path for the scheduled LSP. In case no path can be found, an empty ERO is used. The A bit is used in PCUpd message to indicate the activation of the scheduled LSP in case the PCE is responsible for the activation (as per the C bit).

6.3. The PCInitiate Message

An 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 case of scheduled LSP, based on the local policy, PCE MAY convey the scheduled LSP to the PCC by including the scheduled TLVs in the LSP object. Or the PCE would initiate the LSP only at the start time of the scheduled LSP as per the [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 case of scheduled LSP, the scheduled TLVs MUST be carried in the LSP object in PCReq message to request the path computation based on scheduled TED and LSP-DB. A PCC MAY use PCReq message to obtain the scheduled path before delegating the LSP.

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. The negative reply may indicate the reason why no path could be found. In case of scheduled LSP, the scheduled TLVs MUST be carried in the LSP object in PCRep message to indicate the path computation based on scheduled TED and LSP-DB. A PCC and PCE MAY use PCReq and PCRep message to obtain the scheduled path before delegating the LSP.

6.6. The PCErr Message

The Path Computation Error (PCErr) message is a PCEP message as described in [RFC5440] for error reporting. The current document defines new error values for several error types to cover failures specific to scheduling and reuse 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 PCEP speakers have not set the corresponding bits in the STATEFUL-PCE-CAPABILITY TLV in their respective OPEN message. 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 TBD6 (Attempted LSP Scheduling if 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 the scheduled TLVs as unknown and ignore them.

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) with LSP error-value="Unacceptable parameters" in the LSP object (with scheduled TLVs) in the PCRpt message to the PCE.

The scheduled TLVs 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 TBD5 (Scheduled TLV missing).

7. Implementation Status

[NOTE TO RFC EDITOR : This whole section and the reference to RFC 7942 is to be removed before publication as an RFC]

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in [RFC7942]. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to [RFC7942], "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit".

At the time of posting the -09 version of this document, there are no known implementations of this mechanism. It is believed that two vendors/organizations are considering prototype implementations, but these plans are too vague to make any further assertions.

8. Security Considerations

This document defines 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 as 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 deployment should employ suitable PCEP security mechanisms like TCP Authentication Option (TCP-AO) [RFC5925] or [RFC8253]. The procedure based on Transport Layer Security (TLS) in [RFC8253] is considered a security enhancement and thus is much better suited for the sensitive information. PCCs may also need to apply some form of rate limit to the processing of scheduled LSPs.

9. Manageability Consideration

9.1. 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.

9.2. Information and Data Models

An implementation SHOULD allow the operator to view the capability defined in this document. To serve this purpose, the PCEP YANG module [I-D.ietf-pce-pcep-yang] could be extended.

9.3. 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].

9.4. Verify Correct Operations

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

9.5. Requirements On Other Protocols

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

9.6. 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].

10. IANA Considerations

10.1. PCEP TLV Type Indicators

This document defines the following new PCEP TLV. IANA maintains a sub-registry "PCEP TLV Type Indicators" in the "Path Computation Element Protocol (PCEP) Numbers" registry. IANA is requested to make the following allocations from this sub-registry.

Value	Meaning	Reference
TBD1	SCHED-LSP-ATTRIBUTE	This document
TBD2	SCHED-PD-LSP-ATTRIBUTE	This document

IANA is requested to create and maintain a new registry "Opt" under SCHED-PD-LSP-ATTRIBUTE (TLV Type: TBD2). Initial values for the registry are given below.

Value	Name	Definition
0	Reserved	
1	REPEAT-EVERY-DAY	Section 5.2.2
2	REPEAT-EVERY-WEEK	Section 5.2.2
3	REPEAT-EVERY-MONTH	Section 5.2.2
4	REPEAT-EVERY-YEAR	Section 5.2.2
5	REPEAT-EVERY-REPEAT-TIME-LENGTH	Section 5.2.2
6-14	Unassigned	
15	Reserved	

10.2. 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 a sub-registry "STATEFUL-PCE-CAPABILITY TLV Flag Field" in the "Path Computation Element Protocol (PCEP) Numbers" registry. IANA is requested to make the following allocations from this sub-registry.

The following values are defined in this document:

Bit	Description	Reference
TBD3	LSP-SCHEDULING-CAPABILITY (B-bit)	This document
TBD4	PD-LSP-CAPABLITY (PD-bit)	This document

10.3. Schedule TLVs Flag Field

IANA is requested to create a new sub-registry, named "Schedule TLVs Flag Field", within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the Flag field in the SCHED-LSP-ATTRIBUTE and SCHED-PD-LSP-ATTRIBUTE TLVs. New values are assigned by Standards Action [RFC8126]. 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
0-4	Unassigned	
5	R-bit	This document
6	C-bit	This document
7	A-bit	This document

10.4. PCEP-Error Object

IANA is requested to allocate 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
   6        Mandatory Object missing

             Error-value
             TBD5:  Scheduled TLV missing

   19       Invalid Operation

             Error-value
             TBD6: Attempted LSP Scheduling if the scheduling
                   capability was not advertised
```

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