        PCEP Extensions for MPLS-TE LSP Automatic Bandwidth Adjustment with
                              Stateful PCE
               draft-ietf-pce-stateful-pce-auto-bandwidth-05

Abstract

   The Path Computation Element Communication Protocol (PCEP) provides
   mechanisms for Path Computation Elements (PCEs) to perform path
   computations in response to Path Computation Clients (PCCs) requests.
    The stateful PCE extensions allow stateful control of Multi-Protocol
   Label Switching (MPLS) Traffic Engineering Label Switched Paths (TE
   LSPs) using PCEP.

   Automatic bandwidth allows automatic and dynamic adjustment of the TE
   LSP bandwidth reservation based on the volume of traffic flowing
   through the LSP. This document describes PCEP extensions for
   automatic bandwidth adjustment when employing an Active Stateful PCE
   for both PCE-Initiated and PCC-Initiated LSPs.

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1. Introduction

   [RFC5440] describes the Path Computation Element Protocol (PCEP) as a
   communication mechanism between a Path Computation Client (PCC) and a
   Path Control Element (PCE), or between PCE and PCE, that enables
   computation of Multi-Protocol Label Switching (MPLS) Traffic
   Engineering Label Switched Paths (TE LSPs).

   [I-D.ietf-pce-stateful-pce] specifies extensions to PCEP to enable
   stateful control of MPLS TE LSPs. It describes two mode of
   operations - Passive stateful PCE and Active stateful PCE. Further,
   [I-D.ietf-pce-pce-initiated-lsp] describes the setup, maintenance and
   teardown of PCE-Initiated LSPs for the stateful PCE model. In this
   document, the focus is on Active stateful PCE where the LSPs are

controlled by the PCE.

Over time, based on the varying traffic pattern, an LSP established with a certain bandwidth may require to adjust the bandwidth reserved in the network automatically. The head-end Label Switch Router (LSR) monitors the actual bandwidth demand of the established LSP and periodically computes new bandwidth. The head-end LSR adjusts the bandwidth reservation of the LSP based on the computed bandwidth automatically. This feature is commonly referred to as Auto-Bandwidth. The Auto-Bandwidth feature is described in detail in Section 4 of this document.

In the model considered in this document, the PCC (head-end of the LSP) collects the traffic rate samples flowing through the LSP and calculates the new adjusted bandwidth. The PCC reports the calculated bandwidth to be adjusted to the PCE. This is similar to the passive stateful PCE model, while the passive stateful PCE uses path request/reply mechanism, the active stateful PCE uses report/update mechanism to adjust the LSP bandwidth. In case of PCE-Initiated LSP, the PCC is requested during the LSP initiation to monitor and calculate the new adjusted bandwidth. [RFC8051] describes the use-case for Auto-Bandwidth adjustment for passive and active stateful PCE.

[I-D.gandhi-pce-pm] describes the PCEP extensions for reporting the performance measurements to the PCE, and includes the real-time bandwidth utilization information of a TE LSP. Those extensions can be used to implement the auto-bandwidth feature on a stateful PCE, i.e. can be used to calculate the new bandwidth to be adjusted on the stateful PCE.

This document defines the PCEP extensions needed to support Auto-Bandwidth feature in a active stateful PCE model where the LSP bandwidth to be adjusted is calculated on the PCC (head-end of the LSP).

2. Conventions Used in This Document

2.1. Requirements Language

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].

2.2. Abbreviations

PCC: Path Computation Client.

   PCE: Path Computation Element.

   PCEP: Path Computation Element Communication Protocol.

   TE LSP: Traffic Engineering Label Switched Path.

2.3. Terminology

   The reader is assumed to be familiar with the terminology defined in
   [RFC5440], [I-D.ietf-pce-pce-initiated-lsp], and [I-D.ietf-pce-
   stateful-pce].

   The following auto-bandwidth terminology is defined in this document.

   Maximum Average Bandwidth (MaxAvgBw): The maximum average bandwidth
      represents the current traffic bandwidth demand of the LSP during
      a time interval. This is the maximum value of the traffic
      bandwidth rate samples (Bandwidth-Samples) in a given
      Adjustment-Interval.

   Adjusted Bandwidth: This is the Auto-Bandwidth computed bandwidth
      that is used to adjust the bandwidth reservation of the LSP.

   Sample-Interval: The periodic time interval at which the measured
      traffic rate of the LSP is collected as a Bandwidth-Sample.

   Bandwidth-Sample: The bandwidth sample of the measured traffic rate
      of the LSP collected at every Sample-Interval.

   Maximum-Bandwidth: The maximum bandwidth that can be reserved for
      the LSP.

   Minimum-Bandwidth: The minimum bandwidth that can be reserved for
      the LSP.

   Up-Adjustment-Interval: The periodic time interval at which the
      bandwidth adjustment should be made using the MaxAvgBw, when
      MaxAvgBw is greater than the current bandwidth reservation of the
      LSP.

   Down-Adjustment-Interval: The periodic time interval at which the
      bandwidth adjustment should be made using the MaxAvgBw, when
      MaxAvgBw is lesser than the current bandwidth reservation of the
      LSP.

   Up-Adjustment-Threshold: This parameter is used to decide when the
      LSP bandwidth should be adjusted. If the percentage or absolute

difference between the current MaxAvgBw and the current bandwidth
reservation is greater than or equal to the threshold value, the
LSP bandwidth is adjusted (upsized) to the current bandwidth
demand (Adjusted Bandwidth) at the Up-Adjustment-Interval expiry.

Down-Adjustment-Threshold: This parameter is used to decide when the
   LSP bandwidth should be adjusted. If the percentage or absolute
   difference between the current bandwidth reservation and the
   current MaxAvgBw is greater than or equal to the threshold value,
   the LSP bandwidth is adjusted (downsized) to the current bandwidth
   demand (Adjusted Bandwidth) at the Down-Adjustment-Interval
   expiry.

Overflow-Count: This parameter is used to decide when the LSP
   bandwidth should be adjusted when there is a sudden increase in
   traffic demand. This value indicates how many times
   consecutively, the percentage or absolute difference between the
   current MaxAvgBw and the current bandwidth reservation of the LSP
   is greater than or equal to the Overflow-Threshold value.

Overflow-Threshold: This parameter is used to decide when the LSP
   bandwidth should be adjusted when there is a sudden increase in
   traffic demand. If the percentage or absolute difference between
   the current MaxAvgBw and the current bandwidth reservation of the
   LSP is greater than or equal to the threshold value, the overflow
   condition is set to be met. The LSP bandwidth is adjusted to the
   current bandwidth demand bypassing the Up-Adjustment-Interval if
   the overflow condition is met consecutively for the Overflow-
   Count.

Underflow-Count: This parameter is used to decide when the LSP
   bandwidth should be adjusted when there is a sudden decrease in
   traffic demand. This value indicates how many times
   consecutively, the percentage or absolute difference between the
   current MaxAvgBw and the current bandwidth reservation of the LSP
   is greater than or equal to the Underflow-Threshold value.

Underflow-Threshold: This parameter is used to decide when the LSP
   bandwidth should be adjusted when there is a sudden decrease in
   traffic demand. If the percentage or absolute difference between
   the current MaxAvgBw and the current bandwidth reservation of the
   LSP is greater than or equal to the threshold value, the underflow
   condition is set to be met. The LSP bandwidth is adjusted to the
   current bandwidth demand bypassing the Down-Adjustment-Interval if
   the underflow condition is met consecutively for the Underflow-
   Count.

Minimum-Threshold: The increase or decrease of the LSP bandwidth

should be at least or above the minimum-threshold represented as
an absolute bandwidth value before the bandwidth adjustment for
the LSP is made. This threshold can be seen as a suppression
threshold that is used along with a percentage threshold to avoid
unnecessary auto-bandwidth adjustments and re-signaling of the LSP
at low bandwidth values.

3. Requirements for PCEP Extensions

The PCEP extensions required for auto-bandwidth are summarized in the
following table.

```
+-------------------------------+-------------------------------+
| PCC Initiated                 | PCE Initiated                 |
+-------------------------------+-------------------------------+
|                               |                               |
| PCC monitors the traffic      | At the time of initiation,    |
| and reports the calculated    | PCE request PCC to monitor    |
| bandwidth to be adjusted      | the traffic and report the    |
| to the PCE.                   | calculated bandwidth to be    |
|                               | adjusted to the PCE.          |
|                               |                               |
| Extension is needed for PCC   | Extension is needed for PCE   |
| to pass on the adjustment     | to pass on the adjustment     |
| parameters at the time of     | parameters at the time of     |
| Delegation.                   | Initiation.                   |
|                               |                               |
+-------------------------------+-------------------------------+
```

             Table 1: Auto-Bandwidth PCEP extensions

The PCEP speaker supporting this document must have a mechanism to
advertise the automatic bandwidth adjustment capability for both PCC-
Initiated and PCE-Initiated LSPs.

Auto-bandwidth deployment considerations for PCEP extensions are
summarized below:

o It is required to identify and inform the PCC, the LSP that are
   enabled with Auto-Bandwidth feature. Not all LSPs in some
   deployments would like their bandwidth to be dependent on the
   real-time bandwidth usage but be constant as set by the operator.

o In addition, an operator should be able to specify the auto-
   bandwidth adjustment parameters (i.e. configuration knobs) to
   control this feature (e.g. minimum/ maximum bandwidth range). The
   PCC should be informed about these adjustment parameters.

4. **Architectural Overview**

4.1. **Auto-Bandwidth Overview**

   Auto-Bandwidth feature allows automatic and dynamic adjustment of the
   reserved bandwidth of an LSP over time, i.e. without network operator
   intervention to accommodate the varying traffic demand of the LSP.
   If the traffic flowing through the LSP is lower than the configured
   or current bandwidth of the LSP, the extra bandwidth is being
   reserved needlessly and being wasted. Conversely, if the actual
   traffic flowing through the LSP is higher than the configured or
   current bandwidth of the LSP, it can potentially cause congestion or
   packet loss in the network. The initial LSP bandwidth can be set to
   an arbitrary value (including zero), in practice, it can be operator
   expected value based on design and planning. The head-end Label
   Switch Router (LSR) monitors the actual traffic flowing through the
   LSP and uses that information to adjust the bandwidth reservation of
   the LSP in the network. The bandwidth adjustment uses the make-
   before-break (MBB) signaling method so that there is no disruption to
   the traffic flow carried by the LSP.

4.2. **Auto-bandwidth Theory of Operation**

   When the Auto-Bandwidth feature is enabled, the measured traffic rate
   is periodically sampled at each Sample-Interval (which can be
   configured by an operator and the default value as 5 minutes) by the
   PCC which is the head-end node of the LSP. The traffic rate samples
   are accumulated over the Adjustment-Interval period (which can be
   configured by an operator and the default value as 24 hours). The
   PCC, in-charge of calculating the bandwidth to be adjusted, will
   adjust the bandwidth of the LSP to the highest traffic rate sample
   (MaxAvgBw) amongst the set of bandwidth samples collected over the
   adjustment-interval period (in the Up or Down direction).

   Note that the highest traffic rate sample could be higher or lower
   than the current LSP bandwidth. Only if the difference between the
   current bandwidth demand (MaxAvgBw) and the current bandwidth
   reservation is greater than or equal to the Adjustment-Threshold
   (percentage or absolute value) (which can be configured by an
   operator and the default as 5 percentage), the LSP bandwidth is
   adjusted (upsized) to the current bandwidth demand (MaxAvgBw).
   Similarly, if the difference between the current bandwidth
   reservation and the current bandwidth demand (MaxAvgBw) is greater
   than or equal to the Down-Adjustment-Threshold (percentage or
   absolute value), the LSP bandwidth is adjusted (downsized) to the
   current bandwidth demand (MaxAvgBw). Some LSPs are less eventful
   while other LSPs may encounter a lot of changes in the traffic
   pattern. The thresholds and intervals for bandwidth adjustment are

configured based on the traffic pattern of the LSP.

In order to avoid frequent re-signaling, an operator may set a longer
adjustment-interval value (Up and/or Down). However, longer
adjustment-interval can result in an undesirable effect of masking
sudden changes in traffic demands of an LSP. To avoid this, the
Auto-Bandwidth feature may pre-maturely expire the adjustment-
interval and adjust the LSP bandwidth to accommodate the sudden
bursts of increase in traffic demand as an overflow condition or
decrease in traffic demand as an underflow condition. An operator
needs to configure appropriate values for the Overflow-Threshold
and/or Underflow-Threshold parameters and they do not have default
values defined in this document.

All thresholds in this document could be represented in both absolute
value and percentage, and could be used together. This is provided
to accommodate the cases where the LSP bandwidth reservation may
become very large or very small over time. For example, an operator
may use the percentage threshold to handle small to large bandwidth
values and absolute values to handle very large bandwidth values.
The auto-bandwidth adjustment is made when either one of the two
thresholds, the absolute or percentage, is crossed.

When using the (adjustment/overflow/underflow) percentage thresholds,
if the LSP bandwidth changes rapidly at very low values, it may
trigger frequent auto-bandwidth adjustments due to the crossing of
the percentage thresholds. This can lead to unnecessary re-signaling
of the LSPs in the network. This is suppressed by setting the
minimum-threshold parameters along with the percentage thresholds.
The auto-bandwidth adjustment is only made if the LSP bandwidth
crosses both the percentage threshold and the minimum-threshold
parameters.

4.3. Scaling Considerations

It should be noted that any bandwidth change requires re-signaling of
an LSP in a make-before-break fashion, which can further trigger
preemption of lower priority LSPs in the network. When deployed
under scale, this can lead to a signaling churn in the network. The
Auto-bandwidth application algorithm is thus advised to take this
into consideration before adjusting the LSP bandwidth. Operators are
advised to set the values of various auto-bandwidth adjustment
parameters appropriate for the deployed LSP scale.

If a PCE gets overwhelmed, it can notify the PCC to temporarily
suspend the reporting of the new LSP bandwidth to be adjusted (see
Section 5.7 of this document). Similarly, if a PCC gets overwhelmed

   due to signaling churn, it can notify the PCE to temporarily suspend
   new LSP setup requests.

5. Extensions to the PCEP

5.1. Capability Advertisement

   During PCEP Initialization Phase, PCEP speakers (PCE or PCC)
   advertise their support of Automatic Bandwidth adjustment feature. A
   PCEP speaker includes the "Auto-Bandwidth Capability" TLV, in the
   OPEN Object to advertise its support for PCEP Auto-Bandwidth
   extensions. The presence of the "Auto-Bandwidth Capability" TLV in
   the OPEN Object indicates that the Automatic Bandwidth feature is
   supported as described in this document.

   o The PCEP protocol extensions for Auto-Bandwidth adjustments MUST
      NOT be used if one or both PCEP speakers have not included the
      "Auto-Bandwidth Capability" TLV in their respective OPEN message.

   o The PCEP speaker that does not recognize the extensions defined in
      this document sends the PCErr message with error-type 2
      (capability not supported) as per Section 6.9 in [RFC5440].

   o If the PCEP speaker that supports the extensions defined in this
      document but did not advertise this capability, then upon receipt
      of AUTO-BANDWIDTH-ATTRIBUTES TLV in the LSPA object, it SHOULD
      generate a PCErr with error-type 19 (Invalid Operation), error-
      value TBD4 (Auto-Bandwidth capability was not advertised) and
      ignore the AUTO-BANDWIDTH-ATTRIBUTES TLV.

5.1.1. AUTO-BANDWIDTH-CAPABILITY TLV

   The AUTO-BANDWIDTH-CAPABILITY TLV is an optional TLV for use in the
   OPEN Object for Automatic Bandwidth Adjustment via PCEP capability
   advertisement. Its format 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=TBD2          |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Flags                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                   AUTO-BANDWIDTH-CAPABILITY TLV format

   The Type of the TLV is (TBD2) and it has a fixed Length of 4 octets.

The value comprises a single field - Flags (32 bits). No flags are
defined for this TLV in this document.

Unassigned bits are considered reserved. They MUST be set to 0 on
transmission and MUST be ignored on receipt.

Advertisement of the Auto-Bandwidth capability TLV implies support of
auto-bandwidth adjustment, as well as the objects, TLVs and
procedures defined in this document.

5.2. AUTO-BANDWIDTH-ATTRIBUTES TLV

The AUTO-BANDWIDTH-ATTRIBUTES TLV provides the 'configurable knobs'
of the feature and it can be included as an optional TLV in the LSPA
Object (as described in [RFC5440]).

For PCE-Initiated LSP [I-D.ietf-pce-pce-initiated-lsp], this TLV is
included in the LSPA Object with the PCInitiate message. For the
PCC-Initiated delegated LSPs, this TLV is carried in the PCRpt
message in LSPA Object. This TLV is also carried in the LSPA object
with the PCUpd message to direct the PCC (LSP head-end) to make
updates to auto-bandwidth attributes such as Adjustment-Interval.

The TLV is encoded in all PCEP messages for the LSP while the auto-
bandwidth adjustment feature is enabled, the absence of the TLV
indicates the PCEP speaker wish to disable the feature.

The format of the AUTO-BANDWIDTH-ATTRIBUTES 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=TBD1            |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                         sub-TLVs                            //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
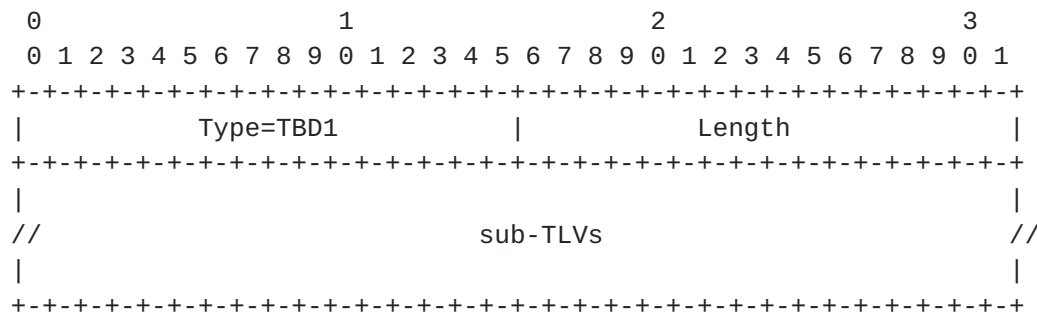
                 AUTO-BANDWIDTH-ATTRIBUTES TLV format

Type: TBD1

Length: The Length field defines the length of the value portion
        in octets as per [RFC5440].

Value: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

```
Type Len Name
   ---------------------------------------------------------------------
    1   4    Sample-Interval sub-TLV
    2   4    Adjustment-Interval sub-TLV
    3   4    Down-Adjustment-Interval sub-TLV
    4   4    Adjustment-Threshold sub-TLV
    5   8    Adjustment-Threshold-Percentage sub-TLV
    6   4    Down-Adjustment-Threshold sub-TLV
    7   8    Down-Adjustment-Threshold-Percentage sub-TLV
    8   4    Minimum-Bandwidth sub-TLV
    9   4    Maximum-Bandwidth sub-TLV
   10   8    Overflow-Threshold sub-TLV
   11   8    Overflow-Threshold-Percentage sub-TLV
   12   8    Underflow-Threshold sub-TLV
   13   8    Underflow-Threshold-Percentage sub-TLV
```

Future specification can define additional sub-TLVs.

The sub-TLVs are encoded to inform the PCEP peer the various sampling
and adjustment parameters. If sub-TLVs are not present, the default
values as specified in this document are used or otherwise based on
the local policy are assumed.

All sub-TLVs are optional and any unrecognized sub-TLV MUST be
silently ignored. If a sub-TLV of same type appears more than once,
only the first occurrence is processed and all others MUST be
ignored.

The following sub-sections describe the sub-TLVs which are currently
defined to be carried within the AUTO-BANDWIDTH-ATTRIBUTES TLV.

5.2.1. Sample-Interval sub-TLV

The Sample-Interval sub-TLV specifies a time interval in seconds at
which traffic samples are collected at the PCC.

```
 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=1              |             Length=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sample-Interval                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Sample-Interval sub-TLV format

The Type is 1, Length is 4 octets, and the value comprises of -

o Sample-Interval: The 4-octet time interval for bandwidth sample
   collection. The valid range is from 1 to 604800, in seconds. The
   default value is 300 seconds. The sample-interval parameter MUST
   NOT be greater than the (down) adjustment-interval.

5.2.2. Adjustment Intervals

The sub-TLVs in this section are encoded to inform the PCEP peer the
adjustment interval parameters. An implementation MAY require to set
different adjustment interval values for when the bandwidth usage
trend is moving upwards or downwards. The Adjustment-Interval sub-
TLV specifies the time interval for both upward and downward trend
(Up-Adjustment-Interval and Down-Adjustment-Interval). If the
operator would like to use a different adjustment interval during the
downward trend, the Down-Adjustment-Interval sub-TLV is included.

5.2.2.1. Adjustment-Interval sub-TLV

The Adjustment-Interval sub-TLV specifies a time interval in seconds
at which bandwidth adjustment should be made when MaxAvgBw is greater
than or less than the current bandwidth reservation of the LSP.

```
 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=2               |            Length=4           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                     Adjustment-Interval                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Adjustment-Interval sub-TLV format

The Type is 2, Length is 4 octets, and the value comprises of -

o Adjustment-Interval: The 4-octet time interval for bandwidth
   adjustments. The valid range is from 1 to 604800, in seconds.
   The default value is 86400 seconds. The adjustment-interval
   parameter MUST NOT be less than the sample-interval.

5.2.2.2. Down-Adjustment-Interval sub-TLV

The Down-Adjustment-Interval sub-TLV specifies a time interval in
seconds at which bandwidth adjustment should be made when MaxAvgBw is
less than the current bandwidth reservation of the LSP. This

parameter overwrites the Adjustment-Interval for the downward trend.

```
 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=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Down-Adjustment-Interval                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                 Down-Adjustment-Interval sub-TLV format

The Type is 3, Length is 4 octets, and the value comprises of -

o Down-Adjustment-Interval: The 4-octet time interval for downward
   bandwidth adjustments. The valid range is from 1 to 604800, in
   seconds. The default value equals the adjustment-interval. The
   down-adjustment-interval parameter MUST NOT be less than the
   sample-interval.

5.2.3. Adjustment Thresholds

The sub-TLVs in this section are encoded to inform the PCEP peer the
adjustment threshold parameters. An implementation MAY include both
sub-TLVs for the absolute value and the percentage, in which case the
bandwidth is adjusted when either of the adjustment threshold
conditions are met. The Adjustment-Threshold sub-TLV specifies the
threshold for both upward and downward trend. If the operator would
like to use a different adjustment threshold during the downward
trend, the Down-Adjustment-Threshold sub-TLV is included. Similarly,
the Adjustment-Threshold-Percentage sub-TLV specifies the threshold
percentage for both upward and downward trend. If the operator would
like to use a different adjustment threshold percentage during the
downward trend, the Down-Adjustment-Threshold-Percentage sub-TLV is
included.

5.2.3.1. Adjustment-Threshold sub-TLV

The Adjustment-Threshold sub-TLV is used to decide when the LSP
bandwidth should be adjusted when MaxAvgBw is greater than or less
than the current bandwidth reservation.

```
 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=4             |             Length=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Adjustment-Threshold                       |
```

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                     Adjustment-Threshold sub-TLV format

   The Type is 4, Length is 4 octets, and the value comprises of -

   o Adjustment-Threshold: The absolute Adjustment-Threshold bandwidth
      value, encoded in IEEE floating point format (see
      [IEEE.754.1985]), expressed in bytes per second. The default
      adjustment-threshold value is not set. Refer to Section 3.1.2 of
      [RFC3471] for a table of commonly used values.

   If the difference between the current MaxAvgBw and the current
   bandwidth reservation is greater than or less than or equal to the
   threshold value, the LSP bandwidth is adjusted to the current
   bandwidth demand (MaxAvgBw).

5.2.3.2. Adjustment-Threshold-Percentage sub-TLV

   The Adjustment-Threshold-Percentage sub-TLV is used to decide when
   the LSP bandwidth should be adjusted when MaxAvgBw is greater than or
   less than the current bandwidth reservation.

```
 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=5              |             Length=8          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Reserved                   | Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Minimum-Threshold                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                Adjustment-Threshold-Percentage sub-TLV format

   The Type is 5, Length is 8 octets, and the value comprises of -

   o Reserved: SHOULD be set to zero on transmission and MUST be
      ignored on receipt.

   o Percentage: The Adjustment-Threshold value (7 bits), encoded in
      percentage (an integer from 1 to 100). The value 0 is considered
      to be invalid. The default value is 5 percent.

   o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value,
      encoded in IEEE floating point format (see [IEEE.754.1985]),
      expressed in bytes per second. The increase or decrease of the
      LSP bandwidth should be at least or above the minimum-threshold

before the bandwidth adjustment is made. The default value is 0.

If the percentage difference between the current MaxAvgBw and the
current bandwidth reservation is greater than or less than or equal
to the threshold percentage, the LSP bandwidth is adjusted to the
current bandwidth demand (MaxAvgBw) (as long as the difference in the
bandwidth is at least or above the Minimum-Threshold).

5.2.3.3. Down-Adjustment-Threshold sub-TLV

The Down-Adjustment-Threshold sub-TLV is used to decide when the LSP
bandwidth should be adjusted when MaxAvgBw is lesser than the current
bandwidth reservation. This parameter overwrites the Adjustment-
Threshold for the downward trend.

```
 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=6               |           Length=4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Down-Adjustment-Threshold                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Down-Adjustment-Threshold sub-TLV format

The Type is 6, Length is 4 octets, and the value comprises of -

o Down-Adjustment-Threshold: The absolute Down-Adjustment-Threshold
   bandwidth value, encoded in IEEE floating point format (see
   [IEEE.754.1985]), expressed in bytes per second. The default
   value equals the adjustment-threshold. Refer to Section 3.1.2 of
   [RFC3471] for a table of commonly used values.

If the difference between current bandwidth reservation and the
current MaxAvgBw is greater than or equal to the threshold value, the
LSP bandwidth is adjusted to the current bandwidth demand (MaxAvgBw).

5.2.3.4. Down-Adjustment-Threshold-Percentage sub-TLV

The Down-Adjustment-Threshold-Percentage sub-TLV is used to decide
when the LSP bandwidth should be adjusted when MaxAvgBw is lesser
than the current bandwidth reservation. This parameter overwrites
the Adjustment-Threshold-Percentage for the downward trend.

```
 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=7               |           Length=8            |
```

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Reserved                   |  Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Minimum-Threshold                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

             Down-Adjustment-Threshold-Percentage sub-TLV format

   The Type is 7, Length is 8 octets, and the value comprises of -

   o Reserved: SHOULD be set to zero on transmission and MUST be
      ignored on receipt.

   o Percentage: The Down-Adjustment-Threshold value (7 bits), encoded
      in percentage (an integer from 1 to 100). The value 0 is
      considered to be invalid. The default value equals the
      adjustment-threshold-percentage.

   o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value,
      encoded in IEEE floating point format (see [IEEE.754.1985]),
      expressed in bytes per second. The decrease of the LSP bandwidth
      should be at least or above the minimum-threshold before the
      bandwidth adjustment is made. The default value equals the
      minimum-threshold for the adjustment-threshold-percentage.

   If the percentage difference between the current bandwidth
   reservation and the current MaxAvgBw is greater than or equal to the
   threshold percentage, the LSP bandwidth is adjusted to the current
   bandwidth demand (MaxAvgBw) (as long as the difference in the
   bandwidth is at least or above the Minimum-Threshold).

5.2.4. Minimum and Maximum Bandwidth Values

5.2.4.1. Minimum-Bandwidth sub-TLV

   The Minimum-Bandwidth sub-TLV specify the minimum bandwidth allowed
   for the LSP, and is expressed in bytes per second. The LSP bandwidth
   cannot be adjusted below the minimum bandwidth value.

```
 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=8              |              Length=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Minimum-Bandwidth                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                   Minimum-Bandwidth sub-TLV format

The Type is 8, Length is 4 octets, and the value comprises of -

o Minimum-Bandwidth: The 4-octet bandwidth value encoded in IEEE
   floating point format (see [IEEE.754.1985]), expressed in bytes
   per second. The default minimum-bandwidth value is set to 0.
   Refer to Section 3.1.2 of [RFC3471] for a table of commonly used
   values.

5.2.4.2. Maximum-Bandwidth sub-TLV

The Maximum-Bandwidth sub-TLV specify the maximum bandwidth allowed
for the LSP, and is expressed in bytes per second. The LSP bandwidth
cannot be adjusted above the maximum bandwidth value.

```
 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=9              |             Length=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Maximum-Bandwidth                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                 Maximum-Bandwidth sub-TLV format

The Type is 9, Length is 4 octets, and the value comprises of -

o Maximum-Bandwidth: The 4-octet bandwidth value encoded in IEEE
   floating point format (see [IEEE.754.1985]), expressed in bytes
   per second. The default maximum-bandwidth value is not set.
   Refer to Section 3.1.2 of [RFC3471] for a table of commonly used
   values.

5.2.5. Overflow and Underflow Conditions

The sub-TLVs in this section are encoded to inform the PCEP peer the
overflow and underflow threshold parameters. An implementation MAY
include sub-TLVs for an absolute value and/or a percentage for the
threshold, in which case the bandwidth is immediately adjusted when
either of the threshold conditions is met consecutively for the given
count (as long as the difference in the bandwidth is at least or
above the Minimum-Threshold). By default, the threshold values for
overflow and underflow conditions are not set.

5.2.5.1. Overflow-Threshold sub-TLV

The Overflow-Threshold sub-TLV is used to decide if the LSP bandwidth
should be adjusted immediately.

```
  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=10            |            Length=8           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      Reserved                  | Count |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      Overflow-Threshold                       |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                  Overflow-Threshold sub-TLV format

   The Type is 10, Length is 8 octets, and the value comprises of -

   o   Reserved: SHOULD be set to zero on transmission and MUST be
       ignored on receipt.

   o   Count: The Overflow-Count value (5 bits), encoded in integer. The
       value 0 is considered to be invalid. The number of consecutive
       samples for which the overflow condition MUST be met for the LSP
       bandwidth to be immediately adjusted to the current bandwidth
       demand, bypassing the (up) adjustment-interval.

   o   Overflow-Threshold: The absolute Overflow-Threshold bandwidth
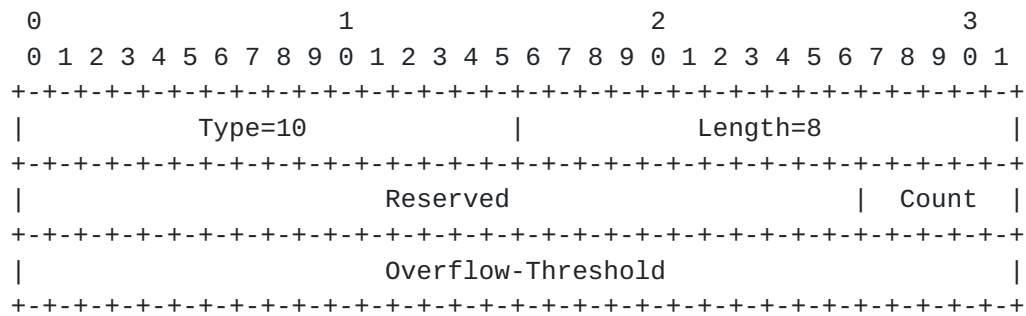   value, encoded in IEEE floating point format (see
       [IEEE.754.1985]), expressed in bytes per second. Refer to Section
       3.1.2 of [RFC3471] for a table of commonly used values. If the
       increase of the current MaxAvgBw from the current bandwidth
       reservation is greater than or equal to the threshold value, the
       overflow condition is met.

5.2.5.2. Overflow-Threshold-Percentage sub-TLV

   The Overflow-Threshold-Percentage sub-TLV is used to decide if the
   LSP bandwidth should be adjusted immediately.

```
  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=11            |            Length=8           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | Percentage |             Reserved              | Count |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      Minimum-Threshold                        |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

             Overflow-Threshold-Percentage sub-TLV format

The Type is 11, Length is 8 octets, and the value comprises of -

o Percentage: The Overflow-Threshold value (7 bits), encoded in
   percentage (an integer from 1 to 100). The value 0 is considered
   to be invalid. If the percentage increase of the current MaxAvgBw
   from the current bandwidth reservation is greater than or equal to
   the threshold percentage, the overflow condition is met.

o Reserved: SHOULD be set to zero on transmission and MUST be
   ignored on receipt.

o Count: The Overflow-Count value (5 bits), encoded in integer. The
   value 0 is considered to be invalid. The number of consecutive
   samples for which the overflow condition MUST be met for the LSP
   bandwidth to be immediately adjusted to the current bandwidth
   demand, bypassing the (up) adjustment-interval.

o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value,
   encoded in IEEE floating point format (see [IEEE.754.1985]),
   expressed in bytes per second. The increase of the LSP bandwidth
   should be at least or above the minimum-threshold before the
   bandwidth adjustment is made.

5.2.5.3. Underflow-Threshold sub-TLV

The Underflow-Threshold sub-TLV is used to decide if the LSP
bandwidth should be adjusted immediately.

```
 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=12             |           Length=8            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Reserved                   |   Count      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Underflow-Threshold                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

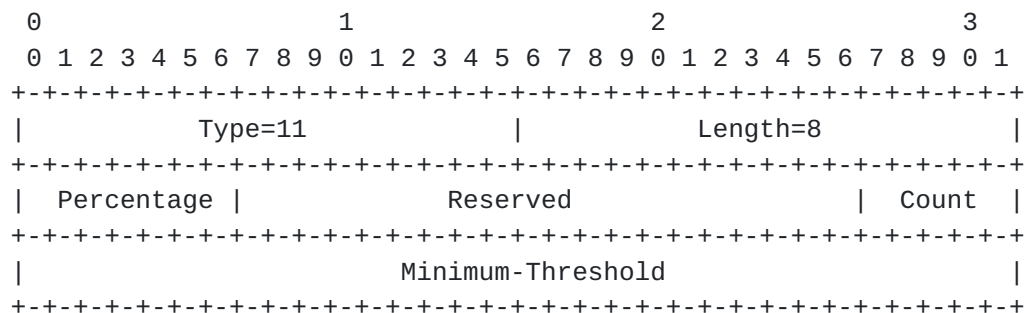   Underflow-Threshold sub-TLV format

The Type is 12, Length is 8 octets, and the value comprises of -

o Reserved: SHOULD be set to zero on transmission and MUST be
   ignored on receipt.

o Count: The Underflow-Count value (5 bits), encoded in integer.
   The value 0 is considered to be invalid. The number of
   consecutive samples for which the underflow condition MUST be met

for the LSP bandwidth to be immediately adjusted to the current
bandwidth demand, bypassing the down-adjustment-interval.

o Underflow-Threshold: The absolute Underflow-Threshold bandwidth
   value, encoded in IEEE floating point format (see
   [IEEE.754.1985]), expressed in bytes per second. Refer to Section
   3.1.2 of [RFC3471] for a table of commonly used values. If the
   decrease of the current MaxAvgBw from the current bandwidth
   reservation is greater than or equal to the threshold value, the
   underflow condition is met.

5.2.5.4. Underflow-Threshold-Percentage sub-TLV

The Underflow-Threshold-Percentage sub-TLV is used to decide if the
LSP bandwidth should be adjusted immediately.

```
 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=13             |           Length=8            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Percentage |            Reserved              | Count  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Minimum-Threshold                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

              Underflow-Threshold-Percentage sub-TLV format

The Type is 13, Length is 8 octets, and the value comprises of -

o Percentage: The Underflow-Threshold value (7 bits), encoded in
   percentage (an integer from 1 to 100). The value 0 is considered
   to be invalid. If the percentage decrease of the current MaxAvgBw
   from the current bandwidth reservation is greater than or equal to
   the threshold percentage, the underflow condition is met.

o Reserved: SHOULD be set to zero on transmission and MUST be
   ignored on receipt.

o Count: The Underflow-Count value (5 bits), encoded in integer.
   The value 0 is considered to be invalid. The number of
   consecutive samples for which the underflow condition MUST be met
   for the LSP bandwidth to be immediately adjusted to the current
   bandwidth demand, bypassing the down-adjustment-interval.

o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value,
   encoded in IEEE floating point format (see [IEEE.754.1985]),
   expressed in bytes per second. The decrease of the LSP bandwidth

should be at least or above the minimum-threshold before the
bandwidth adjustment is made.

5.3. BANDWIDTH Object

As per [RFC5440], the BANDWIDTH object (Object-Class value 5) is
defined with two Object-Type values as following:

o Requested Bandwidth: BANDWIDTH Object-Type value is 1.

o Re-optimization Bandwidth: Bandwidth of an existing TE LSP for
   which a re-optimization is requested. BANDWIDTH Object-Type value
   is 2.

The PCC reports the calculated bandwidth to be adjusted (MaxAvgBw) to
the Stateful PCE using the existing 'Requested Bandwidth' with
BANDWIDTH Object-Type as 1. The reporting of the 're-optimization
bandwidth' with BANDWIDTH Object-Type as 2 is not required as the
Stateful PCE is aware of the existing LSP bandwidth.

5.4. The PCInitiate Message

A PCInitiate message is a PCEP message sent by a PCE to a PCC to
trigger LSP instantiation or deletion
[I.D.ietf-pce-pce-initiated-lsp].

For the PCE-Initiated LSP with Auto-Bandwidth feature enabled, AUTO-
BANDWIDTH-ATTRIBUTES TLV MUST be included in the LSPA object with the
PCInitiate message.

The definition (RBNF) of the PCInitiate message
[I.D.ietf-pce-pce-initiated-lsp] is unchanged by this document.

5.5. The PCUpd Message

A PCUpd message is a PCEP message sent by a PCE to a PCC to update
the LSP parameters [I-D.ietf-pce-stateful-pce].

For PCE-Initiated LSPs with Auto-Bandwidth feature enabled, AUTO-
BANDWIDTH-ATTRIBUTES TLV MUST be included in the LSPA object with the
PCUpd message. The PCE can send this TLV to direct the PCC to change
the auto-bandwidth parameters.

The definition (RBNF) of the PCUpd message
[I-D.ietf-pce-stateful-pce] is unchanged by this document.

5.6. The PCRpt Message

The PCRpt message [I-D.ietf-pce-stateful-pce] is a PCEP message sent
by a PCC to a PCE to report the status of one or more LSPs.

For PCE-Initiated LSPs [I.D.ietf-pce-pce-initiated-lsp], the PCC
creates the LSP using the attributes communicated by the PCE, and
using the local values for the unspecified parameters. After the
successful instantiation of the LSP, PCC automatically delegates the
LSP to the PCE and generates a PCRpt message to provide the status
report for the LSP.

For both PCE-Initiated and PCC-Initiated LSPs, when the LSP is
delegated to a PCE for the very first time as well as after the
successful delegation, the BANDWIDTH object of type 1 is used to
specify the requested bandwidth in the PCRpt message.

For all LSPs with Auto-Bandwidth feature enabled, AUTO-BANDWIDTH-
ATTRIBUTES TLV MUST be included in the LSPA object of the PCRpt
message.

The definition (RBNF) of the PCRpt message
[I-D.ietf-pce-stateful-pce] is unchanged by this document.

5.7. The PCNtf Message

As per [RFC5440], the PCEP Notification message (PCNtf) can be sent
by a PCEP speaker to notify its peer of a specific event.

A PCEP speaker (PCE or PCC) SHOULD notify its PCEP peer (PCC or PCE)
when it is in overwhelmed state due to the auto-bandwidth feature.
Upon receipt of such notification, the peer SHOULD NOT send any PCEP
messages related to auto-bandwidth adjustment. If a PCEP message
related to auto-bandwidth is received during in overwhelmed state, it
MUST be silently ignored.

o When a PCEP speaker is overwhelmed, it SHOULD notify its peer by
   sending a PCNtf message with Notification Type = TBD3 (Auto-
   bandwidth Overwhelm State) and Notification Value = 1 (Entering
   auto-bandwidth overwhelm state). Optionally, OVERLOADED-DURATION
   TLV [RFC5440] MAY be included that specifies the time period
   during which no further PCEP messages related to auto-bandwidth
   adjustment should be sent.

o When the PCEP speaker is no longer in the overwhelm state and is
   available to process the auto-bandwidth adjustments, it SHOULD
   notify its peer by sending a PCNtf message with Notification Type
   = TBD3 (Auto-bandwidth Overwhelm State) and Notification Value = 2
   (Clearing auto-bandwidth overwhelm state).

When Auto-Bandwidth feature is deployed, a PCE can send this
notification to PCC when a PCC is reporting frequent auto-bandwidth
adjustments. If a PCC is overwhelmed with re-signaling, it can also
notify the PCE to not adjust the LSP bandwidth while in overwhelm
state.

6. Security Considerations

This document defines AUTO-BANDWIDTH-CAPABILITY TLV and
AUTO-BANDWIDTH-ATTRIBUTES TLV which do not add any new security
concerns beyond those discussed in [RFC5440] and
[I-D.ietf-pce-stateful-pce] in itself. Some deployments may find the
auto-bandwidth information as extra sensitive as it could be used to
influence LSP path computation and LSP setup with adverse effect.
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. Thus, such
deployment should employ suitable PCEP security mechanisms like TCP
Authentication Option (TCP-AO) [RFC5925] or [I-D.ietf-pce-pceps].

7. Manageability Considerations

7.1. Control of Function and Policy

The Auto-Bandwidth feature SHOULD be controlled per LSP (at PCC
(head-end of the LSP) or PCE) and the values for auto-bandwidth
parameters e.g. sample-interval, adjustment-interval (up/down),
minimum-bandwidth, maximum-bandwidth, adjustment-threshold (up/down)
SHOULD be configurable by an operator.

7.2. Information and Data Models

A Management Information Base (MIB) module for modeling PCEP is
described in [RFC7420]. However, one may prefer the mechanism for
configuration using YANG data model [I-D.ietf-pce-pcep-yang]. These
SHOULD be enhanced to provide controls and indicators for support of
auto-bandwidth feature. Support for various configuration knobs as
well as counters of messages sent/received containing the TLVs
defined in this document SHOULD be added.

7.3. Liveness Detection and Monitoring

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

7.4. Verify Correct Operations

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

7.5. Requirements On Other Protocols

The mechanisms defined in this document do not add any new
requirements on other protocols.

7.6. Impact On Network Operations

In order to avoid any unacceptable impact on network operations, an
implementation SHOULD allow a limit to be placed on the number of
LSPs that can be enabled with auto-bandwidth feature. An
implementation MAY allow a limit to be placed on the rate of auto-
bandwidth related messages sent by a PCEP speaker and received by a
peer. An implementation MAY also allow sending a notification when a
PCEP speaker is overwhelmed or the rate of messages reach a
threshold.

8. IANA Considerations

8.1. PCEP TLV Type Indicators

This document defines the following new PCEP TLVs; IANA is requested
to make the following allocations from the "PCEP TLV Type Indicators"
sub-registry of the PCEP Numbers registry, as follows:

```
Value   Name                                      Reference
-------------------------------------------------------------------
TBD2    AUTO-BANDWIDTH-CAPABILITY                 [This document]
TBD1    AUTO-BANDWIDTH-ATTRIBUTES                 [This document]
```

8.2. AUTO-BANDWIDTH-CAPABILITY TLV Flag Field

IANA is requested to create a sub-registry to manage the Flag field
of the AUTO-BANDWIDTH-CAPABILITY TLV.

New bit numbers are allocated only by an IETF Review 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

There is no bit defined for the AUTO-BANDWIDTH-CAPABILITY TLV Object
flag field in this document.

8.3. AUTO-BANDWIDTH-ATTRIBUTES Sub-TLV

This document specifies the AUTO-BANDWIDTH-ATTRIBUTES Sub-TLVs. IANA
is requested to create an "AUTO-BANDWIDTH-ATTRIBUTES Sub-TLV Types"
sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs
carried in the AUTO-BANDWIDTH-ATTRIBUTES TLV. New sub-TLV are
allocated only by an IETF Review action [RFC5226].

This document defines the following types:

```
Type Name                                     Reference
-------------------------------------------------------------------
 0   Reserved                                 [This document]
 1   Sample-Interval sub-TLV                  [This document]
 2   Adjustment-Interval sub-TLV              [This document]
 3   Down-Adjustment-Interval sub-TLV         [This document]
 4   Adjustment-Threshold sub-TLV             [This document]
 5   Adjustment-Threshold-Percentage sub-TLV  [This document]
```

```
 6   Down-Adjustment-Threshold sub-TLV            [This document]
 7   Down-Adjustment-Threshold-Percentage sub-TLV [This document]
 8   Minimum-Bandwidth sub-TLV                    [This document]
 9   Maximum-Bandwidth sub-TLV                    [This document]
10   Overflow-Threshold sub-TLV                   [This document]
11   Overflow-Threshold-Percentage sub-TLV        [This document]
12   Underflow-Threshold sub-TLV                  [This document]
13   Underflow-Threshold-Percentage sub-TLV       [This document]
14-  Unassigned                                   [This document]
65535
```

8.4. Error Object

This document defines a new Error-Value for PCErr message of Error-Type 19 (Invalid Operation) [I-D.ietf-pce-stateful-pce]; IANA is requested to allocate new error-value within the "PCEP-ERROR Object Error Types and Values" subregistry of the PCEP Numbers registry, as follows:

```
Error-Type Meaning & error values                Reference
------------------------------------------------------------------
19         Invalid Operations

           Error-Value = TBD4:               [This document]
           Auto-Bandwidth Capability
           was not Advertised
```

8.5. Notification Object

IANA is requested to allocate new Notification Types and Notification Values within the "Notification Object" sub-registry of the PCEP Numbers registry, as follows:

```
Type        Meaning                            Reference
------------------------------------------------------------------
TBD3        Auto-Bandwidth Overwhelm State     [This document]

            Notification-value=1:   Entering Auto-Bandwidth
                                    overwhelm state
            Notification-value=2:   Clearing Auto-Bandwidth
                                    overwhelm state
```

9. References

9.1. Normative References

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

   [RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an
              IANA Considerations Section in RFCs", BCP 26, RFC 5226,
              May 2008.

   [RFC5440] Vasseur, JP. and JL. Le Roux, "Path Computation Element
              (PCE) Communication Protocol (PCEP)", RFC 5440, March
              2009.

   [I-D.ietf-pce-stateful-pce] Crabbe, E., Minei, I., Medved, J., and
              R. Varga, "PCEP Extensions for Stateful PCE", draft-ietf-
              pce-stateful-pce (work in progress).

   [I-D.ietf-pce-pce-initiated-lsp] Crabbe, E., Minei, I., Sivabalan,
              S., and R. Varga, "PCEP Extensions for PCE-initiated LSP
              Setup in a Stateful PCE Model", draft-ietf-pce-pce-
              initiated-lsp (work in progress).

9.2. Informative References

   [RFC3471] Berger, L., "Generalized Multi-Protocol Label Switching
              (GMPLS) Signaling Functional Description", RFC 3471,
              January 2003.

   [RFC5925] Touch, J., Mankin, A., and R. Bonica, "The TCP
              Authentication Option", RFC 5925, June 2010.

   [RFC7420] Koushik, A., Stephan, E., Zhao, Q., King, D., and J.
              Hardwick, "Path Computation Element Communication Protocol
              (PCEP) Management Information Base (MIB) Module", RFC
              7420, December 2014.

   [RFC8051] Zhang, X. and I. Minei, "Applicability of a Stateful Path
              Computation Element (PCE)", RFC 8051, January 2017.

   [I-D.ietf-pce-pceps] Lopez, D., Dios, O., Wu, W., and D. Dhody,
              "Secure Transport for PCEP", draft-ietf-pce-pceps (work in
              progress).

   [I-D.ietf-pce-pcep-yang] Dhody, D., Hardwick, J., Beeram, V., and J.
              Tantsura, "A YANG Data Model for Path Computation Element
              Communications Protocol (PCEP)", draft-ietf-pce-pcep-yang

(work in progress).

[I-D.gandhi-pce-pm] Gandhi, R., Wen, B., Barth, C., and D. Dhody,
            "PCEP Extensions for Reporting MPLS-TE LSP Performance
            Measurements", draft-gandhi-pce-pm (work in progress).

[IEEE.754.1985] Institute of Electrical and Electronics Engineers,
            "Standard for Binary Floating-Point Arithmetic", IEEE
            Standard 754, August 1985.

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