     PCEP Extensions for MPLS-TE LSP Automatic Bandwidth Adjustment with
                               Stateful PCE
                draft-dhody-pce-stateful-pce-auto-bandwidth-08

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.

   This document describes PCEP extensions for automatic bandwidth
   adjustment when employing an Active Stateful PCE for both PCE-
   initiated and PCC-initiated LSPs. In one of the models described,
   PCC computes the bandwidth to be adjusted and informs the PCE whereas
   in the second model, PCC reports the real-time bandwidth usage to a
   PCE and the PCE computes the adjustment bandwidth.

Status of This Memo

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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. In this
   document, the focus is on Active stateful PCE where LSPs are
   configured at the PCC and control over them is delegated to the PCE.
   Further [I-D.ietf-pce-pce-initiated-lsp] describes the setup,

maintenance and teardown of PCE-initiated LSPs for the stateful PCE
model.

Over time, based on the varying traffic pattern, an LSP established
with certain bandwidth may require to adjust the bandwidth, reserved
in the network automatically. Ingress Label Switch Router (LSR)
collects the traffic rate at each sample interval to determine the
bandwidth demand of the LSP. This bandwidth information is then used
to adjust the LSP bandwidth periodically. This feature is commonly
referred to as Auto-Bandwidth.

Enabling Auto-Bandwidth feature on an LSP results in the LSP
automatically adjusting its bandwidth reservation based on the actual
traffic flowing through the LSP. 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. Once the LSP
is set-up, the LSP monitors the traffic flow and adjusts its
bandwidth every adjustment-interval period. The bandwidth adjustment
uses the make-before-break signaling method so that there is no
interruption to the traffic flow. The Auto-Bandwidth is described in
detail in Section 4.1. [I-D.ietf-pce-stateful-pce-app] describes the
use-case for Auto-Bandwidth adjustment for passive and active
stateful PCE.

In this document, following deployment models are considered for
employing Auto-Bandwidth feature with active stateful PCE.

o Deployment model 1: PCC to decide adjusted bandwidth:

   * In this model, the PCC (head-end of the LSP) monitors and
      calculates the new adjusted bandwidth. The PCC reports the
      calculated bandwidth to be adjusted to the PCE.

   * This approach would be similar to 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.

   * For PCE-initiated LSP, the PCC is requested during the LSP
      initiation to monitor and calculate the new adjusted bandwidth.

o Deployment model 2: PCE to decide adjusted bandwidth:

   * In this model, the PCE calculates the new adjusted bandwidth
      for the LSP.

   * Active stateful PCE can use information such as historical

trending data, application-specific information about expected
demands and central policy information along with real-time
bandwidth usage to make smarter bandwidth adjustment to the
delegated LSPs. Since the LSP has delegated control to the
PCE, it is inherently suited that it should be the stateful PCE
that decides the bandwidth adjustments.

* For PCE-initiated LSP, the PCC is requested during initiation,
   to monitor and report the real-time bandwidth usage.

* This model does not exclude use of any other mechanism employed
   by stateful PCE to learn real-time bandwidth usage information.
    But at the same time, using the same protocol (PCEP in this
   case) for updating and reporting the adjustment parameters as
   well as to learn real-time bandwidth usage is operationally
   beneficial.

This document defines extensions needed to support Auto-Bandwidth
feature on the LSPs in a active stateful PCE model using PCEP.

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. Terminology

The following terminology is used in this document.

Active Stateful PCE: PCE that uses tunnel state information learned
   from PCCs to optimize path computations. Additionally, it
   actively updates tunnel parameters in those PCCs that delegated
   control over their tunnels to the PCE.

Delegation: An operation to grant a PCE temporary rights to modify a
   subset of tunnel parameters on one or more PCC's tunnels. Tunnels
   are delegated from a PCC to a PCE.

PCC: Path Computation Client. Any client application requesting a
   path computation to be performed by a Path Computation Element.

PCE: Path Computation Element. An entity (component, application,
   or network node) that is capable of computing a network path or
   route based on a network graph and applying computational

constraints.

TE LSP: Traffic Engineering Label Switched Path.

Note the Auto-Bandwidth feature specific terms defined in Section
4.1.

3. Requirements for PCEP Extensions

The PCEP speaker supporting this document MUST have a mechanism to
advertise the automatic bandwidth adjustment capability.

As discussed in Section 1, there are two deployment models considered
in this document for automatic bandwidth adjustments in case of
active stateful PCE. In the model 1, where PCC decides the adjusted
bandwidth, PCC reports the new adjusted bandwidth and an active
stateful PCE updates the bandwidth of a delegated LSP via existing
mechanisms defined in [I-D.ietf-pce-stateful-pce]. PCEP extensions
required for both models are summarized in the following table.

```
+----------------------------------------------------------------+
| Model 1: PCC decides adjusted BW                               |
+-------------------------------+--------------------------------+
| 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.           |
|                               |                                |
| No new extensions are needed. | Extension is needed for PCE    |
|                               | to pass on the adjustment      |
|                               | parameters at the time of      |
|                               | Initiation.                    |
|                               |                                |
+-------------------------------+--------------------------------+


+----------------------------------------------------------------+
| Model 2: PCC reports bandwidth-usage, PCE decides adjusted BW  |
+-------------------------------+--------------------------------+
|  PCC Initiated                | PCE Initiated                  |
+-------------------------------+--------------------------------+
|                               |                                |
| PCC monitors bandwidth usage  | At the time of initiation,     |
| and reports the real-time     | PCE request PCC to monitor     |
```

bandwidth usage to the PCE.	the traffic and reports the
It is PCE that decides the	real-time bandwidth usage to
calculated bandwidth to be	the PCE. It is PCE that decides
adjusted and updates the	the calculated bandwidth to
LSP accordingly.	be adjusted and updates the
	LSP accordingly.
Extension is needed for	Extension is needed for PCE
PCC to pass on the auto-bw	to pass on the real-time
adjustment parameters at	bandwidth usage reporting
the time of delegation to	parameters at the time of
PCE.	Initiation.
Further extension to report	Further extension to report
the bandwidth-usage to	the bandwidth-usage to
PCE are also needed	PCE are also needed.
+---------------------------------+---------------------------------+

                 Table 1: Auto-Bandwidth PCEP extensions

   Further Auto-Bandwidth deployment considerations are summarized
   below:

   o It is required to identify and inform the PCEP peer, 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 It is also required to identify and inform the PCEP peer the model
      of operation i.e. if PCC decides the adjusted bandwidth, or PCC
      reports the real-time bandwidth usage instead and the PCE decides
      the adjusted bandwidth.

      * Note that PCEP extension for reporting real-time bandwidth
         usage, as specified in this document, is one of the ways for a
         PCE to learn this information. But at the same time a stateful
         PCE may choose to learn this information from other means like
         management, performance tools, which are beyond the scope of
         this document.

   o Further for the LSP with Auto-Bandwidth feature enabled, an
      operator should be able to specify the adjustment parameters (i.e.
      configuration knobs) to control this feature (e.g. minimum/
      maximum bandwidth range) and PCEP peer should be informed.

4. **Architectural Overview**

4.1. **Auto-Bandwidth Overview**

   Auto-Bandwidth feature allows an LSP to automatically and dynamically
   adjust its reserved bandwidth over time, i.e. without network
   operator intervention. The bandwidth adjustment uses the
   make-before-break signaling method so that there is no interruption
   to the traffic flow.

   The new bandwidth reservation is determined by sampling the actual
   traffic flowing through 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. With
   Auto-Bandwidth feature, the LSP bandwidth can be set to some
   arbitrary value (including zero) during initial setup time, and it
   will be periodically adjusted over time based on the actual bandwidth
   requirement.

   Note the following definitions of the Auto-Bandwidth terms:

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

   Adjusted Bandwidth: This is the Auto-Bandwidth computed bandwidth
      that needs to be adjusted for the LSP.

   Sample-Interval: The periodic time interval at which the traffic
      rate is collected as a sample.

   Bandwidth-Sample (BwSample): The bandwidth sample collected at every
      sample interval to measure the traffic rate.

   Adjustment-Interval: The periodic time interval at which the
      bandwidth adjustment should be made using the MaxAvgBw.

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

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

   Adjustment-Threshold: This value is used to decide when the

   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 to the current bandwidth demand
   (Adjusted Bandwidth) at the adjustment-interval expiry.

   Overflow-Count: This value is used to decide when the 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 is greater than or equal to the
      Overflow-Threshold value.

   Overflow-Threshold: This value is used to decide when the 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 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 adjustment-interval if the
      overflow-condition is met consecutively for the Overflow-Count.

   Underflow-Count: This value is used to decide when the 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 is greater than or equal to the
      Underflow-Threshold value.

   Underflow-Threshold: This value is used to decide when the 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 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 adjustment-interval if the
      underflow-condition is met consecutively for the Underflow-Count.

   Report-Interval: This value indicates the periodic interval when the
      collected real-time bandwidth-usage samples (BwSample) should be
      reported to the stateful PCE via the PCRpt message.

   Report-Threshold: This value is used to decide if the real-time
      bandwidth-usage samples collected should be reported. Only if the
      percentage or the absolute difference between at least one of the
      bandwidth samples collected and the current bandwidth reservation
      is greater than or equal to the threshold value, the bandwidth
      samples collected during the Report-Interval are reported

otherwise the bandwidth sample(s) are skipped.

Report-Flow-Threshold: This value is used to decide when the real-
   time traffic bandwidth samples should be reported immediately when
   there is a sudden change in traffic demand. If the percentage or
   absolute difference between the current bandwidth sample and the
   current bandwidth reservation is greater than or equal to the
   flow-threshold value, the bandwidth usage report condition is said
   to be met. The collected bandwidth usage information is reported
   bypassing the report-interval if the bandwidth usage report
   condition is met consecutively for the Report-Flow-Count.

Report-Flow-Count: This value is used to decide when the bandwidth
   usage collected so far should be reported when there is a sudden
   change in bandwidth usage. This value indicates how many times
   consecutively, the percentage or absolute difference between the
   current bandwidth sample and the current bandwidth reservation is
   greater than or equal to the Report-Flow-Threshold value, all the
   bandwidth samples collected so far are reported to the PCE
   immediately.

4.2. Theory of Operation

The traffic rate is periodically sampled at each sample-interval
(which can be configured by the user and the default value as 5
minutes) by the head-end node of the LSP. The sampled traffic rates
are accumulated over the adjustment-interval period (which can be
configured by the user and the default value as 24 hours). The PCEP
peer which is in-charge of calculating the bandwidth to be adjusted,
will adjust the bandwidth of the LSP to the highest sampled traffic
rate (MaxAvgBw) amongst the set of bandwidth samples collected over
the adjustment-interval.

Note that the highest sampled traffic rate 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), the LSP bandwidth is adjusted to the
current bandwidth demand (MaxAvgBw). Some LSPs are less eventful
while other LSPs may encounter a lot of changes in the traffic
pattern. PCE sets the intervals for reporting and adjustment based
on the traffic pattern of the LSP.

In order to avoid frequent re-signaling, an operator may set a longer
adjustment-interval value. 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.

In case of Deployment model 2, the PCC reports the real-time
bandwidth-usage information and the PCE decides the adjusted
bandwidth. Multiple bandwidth samples are collected every report-
interval, and reported together to the PCE. To avoid reporting minor
changes in real-time bandwidth-usage, report-threshold is used, to
suppress the sending of the collected samples during the report-
interval. The collected samples are reported if at least one sample
crosses the Report-Threshold (percentage or absolute value). In
order to accommodate sudden changes in the bandwidth usage, report-
flow-threshold is employed by pre-maturely expiry of the report-
interval to report the unreported bandwidth samples collected so far.

All thresholds in this document could be represented in both absolute
value and percentage, and could be used together.

4.3. Scaling Considerations

It should be noted that with both deployment models, any bandwidth
change would require 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 and reporting parameters
appropriate for the deployed LSP scale.

There are potential scaling concerns for the model where PCC (ingress
LSR) reports real-time bandwidth usage information to the stateful
PCE for a large number of LSPs. It is recommended to combine
multiple bandwidth samples (BwSamples) using larger report-interval
and report them together to the PCE, thus reducing the number of
PCRpt messages. Further, Report-Threshold can be use to skip
reporting the bandwidth samples for small changes in the bandwidth
values.

The processing cost of monitoring a large number of LSPs at the PCC
and handling bandwidth change requests at PCE should be taken into
consideration. Note that, this will be implementation dependent.

If a PCE gets overwhelmed, it can notify the PCC to temporarily
suspend its auto-bandwidth reporting (see Section 5.7). Similarly if
a PCC gets overwhelmed due to signaling churn, it can notify the PCE
to temporarily suspend the LSP bandwidth adjustment.

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. 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 Adjustment is supported
as described in this document.

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

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=[TBD5]       |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Flags                            |B|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
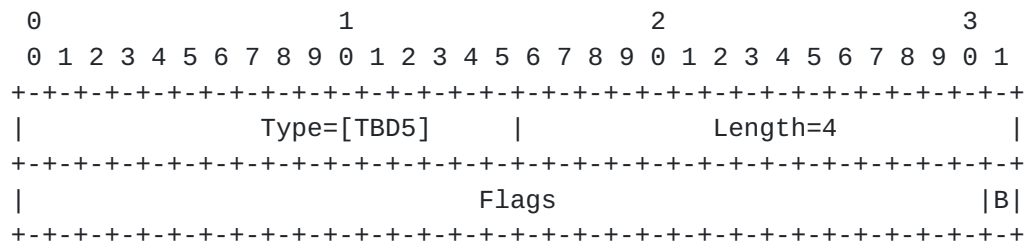
                    AUTO-BANDWIDTH-CAPABILITY TLV format

The type of the TLV is [TBD5] and it has a fixed length of 4 octets.

The value comprises a single field - Flags (32 bits):

o B (bandwidth usage - 1 bit): if set to 1 by a PCC, the B Flag
   indicates that the PCC allows reporting of bandwidth usage
   information; if set to 1 by a PCE, the B Flag indicates that the
   PCE is capable of receiving bandwidth usage information from the

PCC. The BANDWIDTH-USAGE-ATTRIBUTE TLV MUST be encoded when both
PCEP speakers have the B Flag set.

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-ATTRIBUTE TLV

The AUTO-BANDWIDTH-ATTRIBUTE 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 PCInitiate message. For delegated
LSPs, this TLV is carried in PCRpt message in LSPA Object.

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

The format of the AUTO-BANDWIDTH-ATTRIBUTE TLV is shown in the
following figure:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Type=[TBD1]          |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                           sub-TLVs                          //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
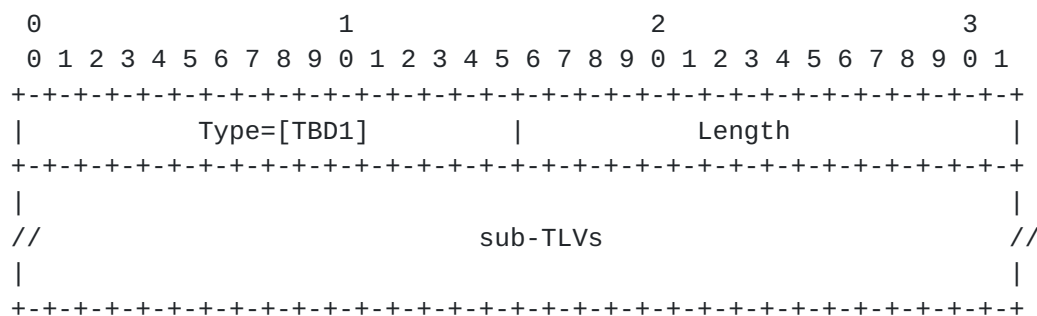
                  AUTO-BANDWIDTH-ATTRIBUTE TLV format

Type: TBD1

Length: Variable

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   Adjustment-Threshold sub-TLV
 4   4   Adjustment-Threshold-Percentage sub-TLV
 5   4   Minimum-Bandwidth sub-TLV
 6   4   Maximum-Bandwidth sub-TLV
 7   8   Overflow-Threshold sub-TLV
 8   4   Overflow-Threshold-Percentage sub-TLV
 9   8   Underflow-Threshold sub-TLV
10   4   Underflow-Threshold-Percentage sub-TLV
```

Future specification can define additional sub-TLVs.

The presence of AUTO-BANDWIDTH-ATTRIBUTE TLV in LSPA Object means
that the automatic bandwidth adjustment feature is enabled. 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 AUTO-BANDWIDTH-ATTRIBUTE TLV can also be carried in PCUpd message
in LSPA Object in order to make updates to auto-bandwidth attributes
such as Adjustment-Interval.

If sub-TLVs are not present, the default values based on the local
policy are assumed.

The sub-TLVs are encoded to inform the PCEP peer the various sampling
and adjustment parameters, and serves the following purpose -

o For PCE-Initiated LSPs, in the Deployment Model 1, inform the PCC
   of the various sampling and adjustment parameters.

o For PCC-Initiated LSPs, in the Deployment Model 2, inform the PCE
   of the various sampling and adjustment parameters.

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

The Type is 1, Length is 4, and the value comprises of 4-octet time
interval, the valid range is from 1 to 604800, in seconds. The
default value is 300 seconds.

```
 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

5.2.2. Adjustment-Interval sub-TLV

The Adjustment-Interval sub-TLV specifies a time interval in seconds
at which bandwidth adjustment should be made.

The Type is 2, Length is 4, and the value comprises of 4-octet time
interval, the valid range is from 1 to 604800, in seconds. The
default value is 300 seconds.

```
 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

5.2.3. Adjustment Threshold

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.

5.2.3.1. Adjustment-Threshold sub-TLV

The Adjustment-Threshold sub-TLV is used to decide when the LSP
bandwidth should be adjusted.

```
 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           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Adjustment Threshold                      |
```

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

                    Adjustment-Threshold sub-TLV format

   The Type is 3, Length is 4, 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. 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 equal to the threshold
      value, the LSP bandwidth is adjusted to the current bandwidth
      demand.

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.

```
 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           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Reserved                     | Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                Adjustment-Threshold-Percentage sub-TLV format

   The Type is 4, Length is 4, 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, encoded in percentage
      (an integer from 0 to 100). If the percentage difference between
      the current MaxAvgBw and the current bandwidth reservation is
      greater than or equal to the threshold percentage, the LSP
      bandwidth is adjusted to the current bandwidth demand.

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.

The Type is 5, Length is 4, and the value comprises of 4-octet
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.

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

                   Minimum-Bandwidth sub-TLV format

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.

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

```
 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           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Maximum-Bandwidth                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                   Maximum-Bandwidth sub-TLV format

5.2.5. Overflow and Underflow Condition

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 the absolute value and the percentage for the
threshold, in which case the bandwidth is immediately adjusted when
either of the adjustment threshold conditions are met consecutively
for the given count.

5.2.5.1. Overflow-Threshold sub-TLV

The Overflow-Threshold sub-TLV is used to decide if the 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=7             |            Length=8           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                  |      Count       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Overflow Threshold                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    Overflow-Threshold sub-TLV format

The Type is 7, Length is 8, 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, 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 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
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=8             |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Percentage |     Reserved                  |      Count       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

               Overflow-Threshold-Percentage sub-TLV format

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

o Percentage: The Overflow-Threshold value, encoded in percentage
   (an integer from 0 to 100). 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, 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 adjustment-interval.

5.2.5.3. Underflow-Threshold sub-TLV

The Underflow-Threshold sub-TLV is used to decide if the 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=9              |           Length=8            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                   |     Count       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Underflow Threshold                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                 Underflow-Threshold sub-TLV format
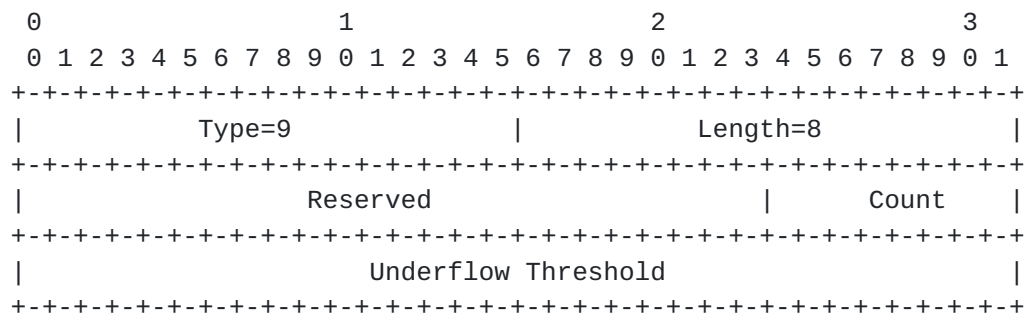
The Type is 9, Length is 8, and the value comprises of -

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

o Count: The Underflow-Count value, 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 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
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=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Percentage |    Reserved                     |     Count     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

            Underflow-Threshold-Percentage sub-TLV format

The Type is 10, Length is 4, and the value comprises of -

o Percentage: The Underflow-Threshold value, encoded in percentage
   (an integer from 0 to 100). 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, 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 adjustment-interval.

5.3. BANDWIDTH-USAGE-ATTRIBUTE TLV

The BANDWIDTH-USAGE-ATTRIBUTE 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 PCInitiate message.

The TLV is encoded in all PCEP messages for the LSP till the
bandwidth usage reporting feature is enabled, the absence of the TLV

indicate the PCEP speaker wish to disable this feature.

The format of the BANDWIDTH-USAGE-ATTRIBUTE TLV is shown in the
following figure:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Type=[TBD2]          |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
//                          sub-TLVs                           //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
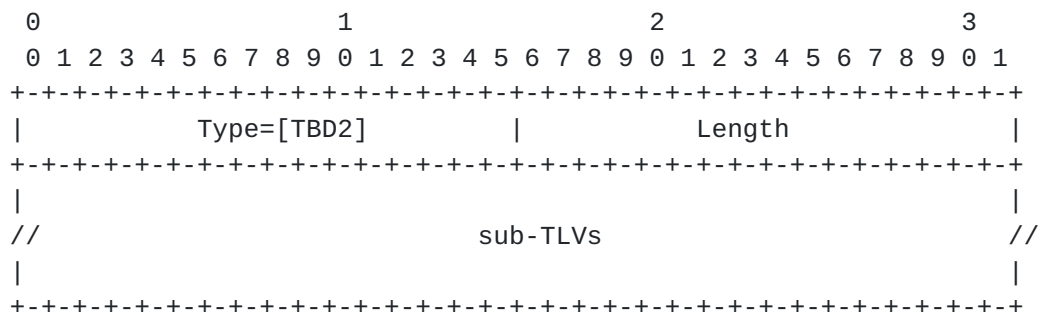
                    BANDWIDTH-USAGE-ATTRIBUTE TLV format

Type: TBD2

Length: Variable

Value: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

```
Type Len Name
----------------------------------------------------------------------
1    4   Bandwidth-Usage-Report-Interval sub-TLV
2    4   Bandwidth-Usage-Report-Threshold sub-TLV
3    4   Bandwidth-Usage-Report-Threshold-Percentage sub-TLV
4    4   Bandwidth-Usage-Report-Flow-Threshold sub-TLV
5    4   Bandwidth-Usage-Report-Flow-Threshold-Percentage sub-TLV
```

Future specification can define additional sub-TLVs.

The presence of BANDWIDTH-USAGE-ATTRIBUTE TLV in LSPA Object means
that the bandwidth usage reporting to PCE is enabled. 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 BANDWIDTH-USAGE-ATTRIBUTE TLV can also be carried in PCUpd
message in LSPA Object in order to make updates to the attributes
such as Bandwidth-Usage-Report-Interval.

If sub-TLVs are not present, the default values based on the local
policy are assumed.

The following sub-sections describe the sub-TLVs which are currently
defined to be carried within the BANDWIDTH-USAGE-ATTRIBUTE TLV, and
serves the following purpose -

o For PCE-Initiated LSPs, in the Deployment Model 2, inform the PCC
   of the various sampling and reporting parameters.

5.3.1. Bandwidth-Usage-Report-Interval sub-TLV

The Bandwidth-Usage-Report-Interval sub-TLV specifies a time
interval in seconds in which collected bandwidth samples should be
reported to PCE.

The Type is 1, Length is 4, and the value comprises of 4-octet
time interval, the valid range is from 1 to 604800, in seconds.
Default value is 3600 seconds.

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Bandwidth-Usage-Report-Interval                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

          Bandwidth-Usage-Report-Interval sub-TLV format

5.3.2. Bandwidth-Usage-Report-Threshold sub-TLV

The Bandwidth-Usage-Report-Threshold sub-TLV is used to decide
when the bandwidth samples collected so far should be reported
immediately, bypassing the report-interval.

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Bandwidth-Usage-Report Threshold                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

          Bandwidth-Usage-Report-Threshold sub-TLV format

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

o Threshold: The absolute 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 or the decrease of at least
   one of the bandwidth samples (BwSamples) collected so far compared
   to the current bandwidth reservation is greater than or equal to
   the threshold value, the bandwidth samples collected so far are
   reported.

5.3.3. Bandwidth-Usage-Report-Threshold-Percentage sub-TLV

The Bandwidth-Usage-Report-Threshold-Percentage sub-TLV is used to
decide when the bandwidth samples collected so far should be reported
immediately, bypassing the report-interval.

```
 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           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                    |  Percentage   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

        Bandwidth-Usage-Report-Threshold-Percentage sub-TLV format

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

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

o Percentage: The threshold value, encoded in percentage (an integer
   from 0 to 100). If the percentage increase or the decrease of at
   least one of the bandwidth sample (BwSample) compared to the
   current bandwidth reservation is greater than or equal to the
   threshold percentage, the bandwidth samples collected so far are
   reported.

5.3.4. Bandwidth-Usage-Report-Flow-Threshold sub-TLV

The Bandwidth-Usage-Report-Flow-Threshold sub-TLV is used to decide
when the bandwidth samples collected should be reported immediately,
bypassing the report-interval.

```
 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=8           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
|                      Reserved                    |      Count      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Bandwidth-Usage-Report-Flow Threshold            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

           Bandwidth-Usage-Report-Flow-Threshold sub-TLV format

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

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

   o Count: The Report-Flow-Count value, encoded in integer. The value
      0 is considered to be invalid. The number of consecutive samples
      for which the bandwidth usage report condition MUST be met for the
      the bandwidth samples collected so far are reported immediately,
      bypassing the report-interval.

   o Threshold: The absolute flow 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 or the decrease of the
      current bandwidth sample (BwSample) compared to the current
      bandwidth reservation is greater than or equal to the flow
      threshold value, bandwidth usage report condition is said to be
      met.

5.3.5. Bandwidth-Usage-Report-Flow-Threshold-Percent sub-TLV

   The Bandwidth-Usage-Report-Flow-Threshold-Percent sub-TLV is used to
   decide when the bandwidth samples collected should be reported
   immediately, bypassing the report-interval.

```
 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=4             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Percentage |    Reserved                      |      Count     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

     Bandwidth-Usage-Report-Flow-Threshold-Percentage sub-TLV format

   The Type is 5, Length is 4, and the value comprises of -

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

o Percentage: The flow threshold value, encoded in percentage (an
   integer from 0 to 100). If the percentage increase or the
   decrease of the current bandwidth sample (BwSample) compared to
   the current bandwidth reservation is greater than or equal to the
   threshold percentage, bandwidth usage report condition is said to
   be met.

o Count: The Report-Flow-Count value, encoded in integer. The value
   0 is considered to be invalid. The number of consecutive samples
   for which the bandwidth usage report condition MUST be met for the
   the bandwidth samples collected so far are reported immediately,
   bypassing the report-interval.

5.4. BANDWIDTH Object

5.4.1. Auto-Bandwidth Adjusted Bandwidth Report

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.

In the first deployment model, where PCC calculates the adjusted
bandwidth, PCC reports the calculated bandwidth to be adjusted
(MaxAvgBw) to the PCE. This is done via the existing 'Requested
Bandwidth with BANDWIDTH Object-Type as 1.

5.4.2. Bandwidth-Usage Report

A new Object-type for BANDWIDTH object is defined to report the real-
time bandwidth usage of a TE LSP.

The Object-type is [TBD3], the object length is variable with
multiples of 4 bytes. The payload format is as follows:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          BwSample1                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             ...                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          BwSampleN                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Bandwidth-Usage format

   o BwSample: The actual bandwidth usage, (the BwSample collected at
      the end of each sample-interval) encoded in IEEE floating point
      format (see [IEEE.754.1985]), expressed in bytes per second.

   The Bandwidth-Usage object-type is used in the second deployment
   model where PCC reports the TE LSP bandwidth usage and the PCE
   decides the Auto-Bandwidth adjusted bandwidth.

   The Bandwidth-Usage object-type can also be used for TE LSPs without
   enabling the Auto-Bandwidth feature, to learn the actual bandwidth
   usage of the LSPs for other applications at the stateful PCE, details
   of which are beyond the scope of this document.

5.5. 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 [I-D.ietf-pce-pce-initiated-lsp] with
   Auto-Bandwidth feature enabled, AUTO-BANDWIDTH-ATTRIBUTE TLV or
   BANDWIDTH-USAGE-ATTRIBUTE TLV MUST be included in the LSPA object
   with the PCInitiate message, depending on the deployment model being
   used. The rest of the processing remains unchanged.

5.6. The PCRpt Message

   As specified in [I.D.ietf-pce-pce-initiated-lsp], the PCC creates the
   LSP using the attributes communicated by the PCE, and local values
   for the unspecified parameters. After the successful instantiation
   of the LSP, PCC automatically delegates the LSP to the PCE and
   generates an LSP State Report (PCRpt) for the LSP.

   When LSP is delegated to a PCE for the very first time, BANDWIDTH
   object of type 1 is used to specify the requested bandwidth in the
   PCRpt message.

   When the LSP is enabled with the Auto-Bandwidth feature using
   Deployment Model 1, PCC SHOULD include the BANDWIDTH object of type 1
   to specify the calculated bandwidth to be adjusted to the PCE in the
   PCRpt message.

   When the LSP is enabled with the Auto-Bandwidth feature using
   Deployment Model 2, PCC SHOULD include the BANDWIDTH object of type

   [TBD3] to report the real-time bandwidth-usage to the PCE in the
   PCRpt message.

   The definition of the PCRpt message (see [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. As
   described in Section 4.3 of this document, a PCEP speaker SHOULD
   notify its PCEP peer that it is overwhelmed, and on receipt of such
   notification the peer SHOULD NOT send any PCEP messages related to
   auto-bandwidth adjustment or bandwidth usage reporting. If a PCEP
   message related to auto-bandwidth adjustment or bandwidth usage
   reporting is received, it MUST be silently ignored.

   When a PCEP speaker is overwhelmed, it SHOULD notify its peer by
   sending a PCNtf message with Notification Type = TBD6 (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 or bandwidth usage
   reporting should be sent. When the PCEP speaker is no longer in the
   overwhelm state and is available to process the auto-bandwidth
   adjustment or bandwidth usage reporting, it SHOULD notify its peer by
   sending a PCNtf message with Notification Type = TBD6 (Auto-bandwidth
   Overwhelm State) and Notification Value = 2 (Clearing auto-bandwidth
   overwhelm state).

   When Auto-Bandwidth feature is deployed using Deployment Model 1, 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/re-routing, it can also notify the PCE to not adjust the
   LSP bandwidth while in overwhelm state.

   When Auto-Bandwidth feature is deployed using Deployment Model 2, a
   PCE can send this notification when a PCC is reporting bandwidth-
   usage too frequently for the PCE to process. In this model as well,
   if a PCC is overwhelmed with re-signaling/re-routing, it can notify
   the PCE to not update bandwidth while in overwhelm state.

6. Security Considerations

   This document defines a new BANDWIDTH object type,
   AUTO-BANDWIDTH-CAPABILITY TLV, AUTO-BANDWIDTH-ATTRIBUTE TLV and

   BANDWIDTH-USAGE-ATTRIBUTE TLV which do not add any new security
   concerns beyond those discussed in [RFC5440] and
   [I-D.ietf-pce-stateful-pce].

   Some deployments may find the reporting of the real-time bandwidth-
   usage information as extra sensitive and thus SHOULD employ suitable
   PCEP security mechanisms like TCP-AO or [I-D.ietf-pce-pceps].

7. Manageability Considerations

7.1. Control of Function and Policy

   The Auto-Bandwidth feature SHOULD be controlled per tunnel (at
   ingress (PCC) or PCE), the values for parameters like sample-
   interval, adjustment-interval, minimum-bandwidth, maximum-bandwidth,
   adjustment-threshold, report-interval, report-threshold SHOULD be
   configurable by an operator.

7.2. Information and Data Models

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

7.3. 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].

7.4. Verify Correct Operations

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

7.5. Requirements On Other Protocols

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

7.6. 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].

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 this registry. <http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators>.

Value	Name	Reference
TBD5	AUTO-BANDWIDTH-CAPABILITY	[This I.D.]
TBD1	AUTO-BANDWIDTH-ATTRIBUTE	[This I.D.]
TBD2	BANDWIDTH-USAGE-ATTRIBUTE	[This I.D.]

8.2. AUTO-BANDWIDTH-CAPABILITY TLV Flag Field

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

New bit numbers may be allocated only by an IETF Consensus action. 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

One bit is defined for the AUTO-BANDWIDTH-CAPABILITY TLV Object flag field in this document:

Bit	Name	Reference
31	Bandwidth usage reporting	[This I.D.]

8.3. AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV

This document specifies the AUTO-BANDWIDTH-ATTRIBUTE Sub-TLVs. IANA is requested to create an "AUTO-BANDWIDTH-ATTRIBUTE Sub-TLV Types" sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs carried in the AUTO-BANDWIDTH-ATTRIBUTE TLV. This document defines the following types:

Type	Name	Reference
0	Reserved	[This I.D.]
1	Sample-Interval sub-TLV	[This I.D.]

```
 2   Adjustment-Interval sub-TLV                  [This I.D.]
 3   Adjustment-Threshold sub-TLV                 [This I.D.]
 4   Adjustment-Threshold-Percentage sub-TLV      [This I.D.]
 5   Minimum-Bandwidth sub-TLV                    [This I.D.]
 6   Maximum-Bandwidth sub-TLV                    [This I.D.]
 7   Overflow-Threshold sub-TLV                   [This I.D.]
 8   Overflow-Threshold-Percentage sub-TLV        [This I.D.]
 9   Underflow-Threshold sub-TLV                  [This I.D.]
10   Underflow-Threshold-Percentage sub-TLV       [This I.D.]
11-  Unassigned                                   [This I.D.]
65535
```

8.4. BANDWIDTH-USAGE-ATTRIBUTE Sub-TLV

This document specifies the BANDWIDTH-USAGE-ATTRIBUTE Sub-TLVs. IANA
is requested to create an "BANDWIDTH-USAGE-ATTRIBUTE Sub-TLV Types"
sub-registry in the "PCEP TLV Type Indicators" for the sub-TLVs
carried in the BANDWIDTH-USAGE-ATTRIBUTE TLV. This document defines
the following types:

```
Type Name                                    Reference
-----------------------------------------------------------------
 0   Reserved                                 [This I.D.]
 1   Bandwidth-Usage-Report-Interval sub-TLV  [This I.D.]
 2   Bandwidth-Usage-Report-Threshold sub-TLV [This I.D.]
 3   Bandwidth-Usage-Report-Threshold-Percentage  [This I.D.]
     sub-TLV
 4   Bandwidth-Usage-Report-Flow-Threshold    [This I.D.]
     sub-TLV
 5   Bandwidth-Usage-Report-Flow-Threshold    [This I.D.]
     -Percentage sub-TLV
 6-  Unassigned                               [This I.D.]
65535
```

8.5. BANDWIDTH Object

This document defines new Object-Type for the BANDWIDTH object
(Object-Class 5, [RFC5440]); IANA is requested to make the following
allocation from this registry.
<http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-objects>.

```
Object-Type Name                             Reference
-----------------------------------------------------------------
 TBD3      Bandwidth-Usage Report            [This I.D.]
```

8.6. Error Object

This document defines a new Error-Value for PCErr message of type 19 (Invalid Operation) [I-D.ietf-pce-stateful-pce]); IANA is requested to make the following allocation from this registry.
<http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-error-object>

```
Error-Value Meaning                                    Reference
----------------------------------------------------------------
 TBD4       Auto-Bandwidth Capability                 [This I.D.]
            was not Advertised
```

8.7. 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
----------------------------------------------------------------
 TBD6       Auto-Bandwidth Overwhelm State            [This I.D.]

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

9. References

9.1. Normative References

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9.2. **Informative References**

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