PCE Working Group   D. Dhody
Internet-Draft   U. Palle
Intended status: Standards Track   Huawei Technologies
Expires: August 26, 2017   R. Singh
                                                  Juniper Networks
                                                          R. Gandhi
                                             Individual Contributor
                                                            L. Fang
                                                               eBay
                                                 February 22, 2017

PCEP Extensions for MPLS-TE LSP Automatic Bandwidth Adjustment with Stateful PCE
draft-ietf-pce-stateful-pce-auto-bandwidth-02

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 certain bandwidth may require to adjust the bandwidth reserved
   in the network automatically. The head-end Label Switch Router (LSR)

   needs to monitor the actual bandwidth demand of the LSP and adjust
   the LSP bandwidth reservation periodically. This feature is commonly
   referred to as Auto-Bandwidth.

   Enabling Auto-Bandwidth feature on an LSP results in the head-end LSR
   automatically adjusting the LSP bandwidth reservation based on the
   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 head-end monitors the traffic flow on the LSP and
   adjusts the bandwidth every adjustment-interval. The bandwidth
   adjustment uses the make-before-break signaling method so that there
   is no disruption to the traffic flow. The Auto-Bandwidth feature is
   described in detail in Section 4.1 of 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 a 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.

   The document [I-D.gandhi-pce-pm] describes the PCEP extensions for
   reporting the performance measurements to the PCE, and includes the
   real-time bandwidth usage 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 extensions needed to support Auto-Bandwidth
   features on the LSPs in a active stateful PCE model using PCEP where
   the bandwidth to be adjusted is calculated on the PCC (the 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. 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 are 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.

   Additional auto-bandwidth PCEP extensions required 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

   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 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 automatic and dynamic adjustment of the
   reserved bandwidth of an LSP over time, i.e. without network operator
   intervention. 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 demand.

   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: The bandwidth sample collected at every sample
   interval to measure the traffic rate.

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.

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.

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

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

4.2. Auto-bandwidth 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 PCC which is 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 PCC (the head-end of the LSP) 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
   period (Up or Down).

   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 Up-Adjustment-Threshold
   (percentage or absolute value), 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 intervals for
   adjustment is 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.

All thresholds in this document could be represented in both absolute
value and percentage, and could be used together. This is done to
accommodate case where the LSP bandwidth reservation may become very
large or very small over time, the two representations help the
operator to provide conditions when the bandwidth usage is too large
or too small.

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). Similarly if a PCC gets overwhelmed due to signaling
churn, it can notify the PCE to temporarily suspend the 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 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=TBD2          |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Flags                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
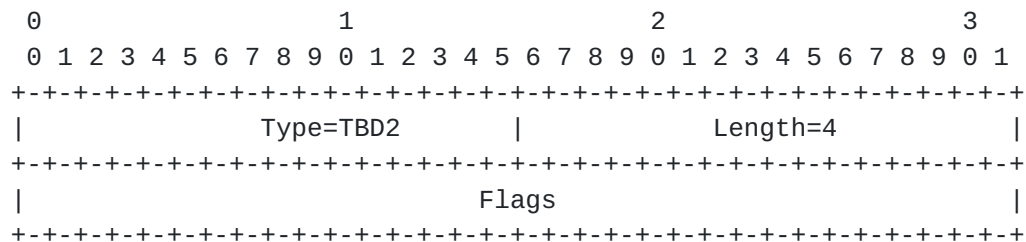
                   AUTO-BANDWIDTH-CAPABILITY TLV format

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). Currently no
flags are defined for this TLV.

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 the PCInitiate message. For the
PCC-Initiated delegated LSPs, this TLV is carried in the PCRpt
message in LSPA Object. This TLV is also included in the LSPA object
with the PCUpd message to direct the PCC (the LSP head-end) to use
different parameters with the LSP.

The TLV is encoded in all PCEP messages for the LSP while 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                          //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
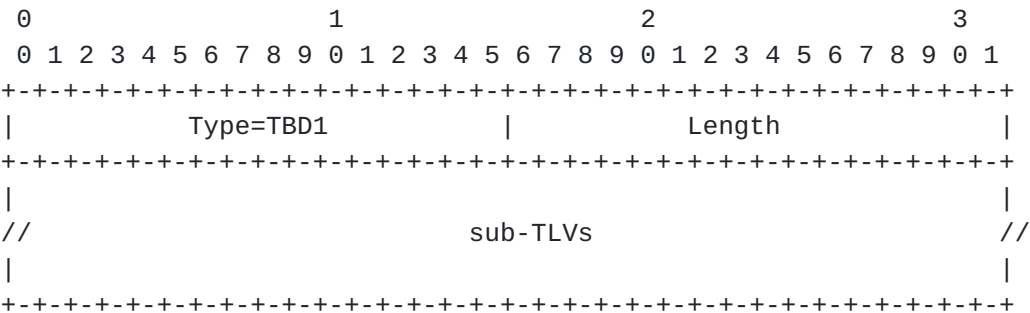
                  AUTO-BANDWIDTH-ATTRIBUTE TLV format

Type: TBD1

Length: The Length field defines the length of the value portion
        in bytes 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   Up-Adjustment-Interval sub-TLV
  3   4   Down-Adjustment-Interval sub-TLV
  4   4   Up-Adjustment-Threshold sub-TLV
  5   4   Up-Adjustment-Threshold-Percentage sub-TLV
  6   4   Down-Adjustment-Threshold sub-TLV
  7   4   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   4   Overflow-Threshold-Percentage sub-TLV
 12   8   Underflow-Threshold sub-TLV
 13   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.

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

The sub-TLVs in this section are encoded to inform the PCEP peer the
adjustment interval parameters. An implementation MAY want to set
different adjustment interval, as the bandwidth usage trend is moving
upwards or downwards. When the TLV is not included default value are
used.

5.2.2.1. Up-Adjustment-Interval sub-TLV

The Up-Adjustment-Interval sub-TLV specifies a time interval in
seconds at which bandwidth adjustment should be made when MaxAvgBw is

greater than the current bandwidth reservation.

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           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Up-Adjustment-Interval                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    Up-Adjustment-Interval sub-TLV format

5.2.2.2. Down-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 less
than the current bandwidth reservation.

The Type is 3, 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=3               |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                 Down-Adjustment-Interval                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                  Down-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. Up-Adjustment-Threshold sub-TLV

The Up-Adjustment-Threshold sub-TLV is used to decide when the LSP
bandwidth should be adjusted when MaxAvgBw is greater 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          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Up-Adjustment-Threshold                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                  Up-Adjustment-Threshold sub-TLV format

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

o Up-Adjustment Threshold: The absolute Up-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 (MaxAvgBw).

5.2.3.2. Up-Adjustment-Threshold-Percentage sub-TLV

The Up-Adjustment-Threshold-Percentage sub-TLV is used to decide when
the LSP bandwidth should be adjusted when MaxAvgBw is greater 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=4          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Reserved                    | Percentage |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

             Up-Adjustment-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 Up-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
(MaxAvgBw).

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.

```
 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, 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. 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).

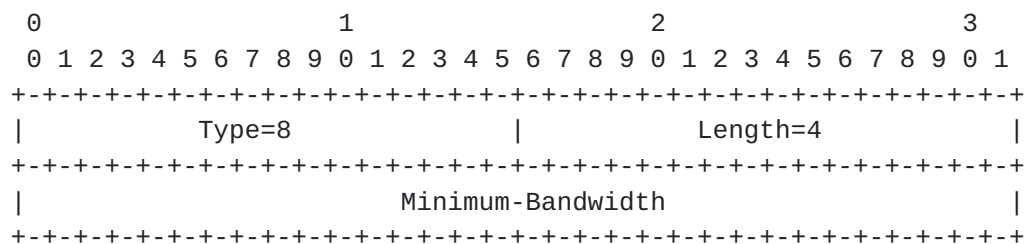### 5.2.3.4. Down-Adjustment-Threshold-Percentage sub-TLV

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.

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

               Down-Adjustment-Threshold-Percentage sub-TLV format

The Type is 7, 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 Down-Adjustment-Threshold value, encoded in
   percentage (an integer from 0 to 100). 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).

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 8, 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=8             |            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 9, 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=9              |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Maximum-Bandwidth                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                    Maximum-Bandwidth sub-TLV format

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

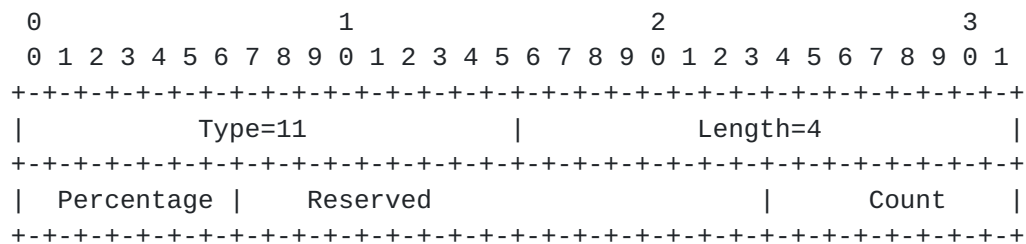   Overflow-Threshold sub-TLV format

   The Type is 10, 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
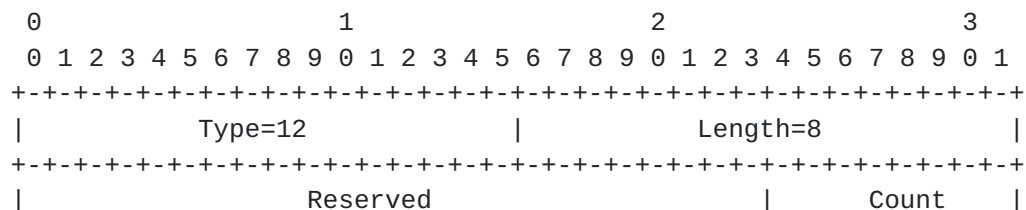bandwidth should be adjusted immediately.

```
 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=11              |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Percentage |    Reserved                    |      Count     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

              Overflow-Threshold-Percentage sub-TLV format

The Type is 11, 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=12              |            Length=8           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Reserved                    |      Count     |
```

```
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                      Underflow-Threshold                     |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                     Underflow-Threshold sub-TLV format

   The Type is 12, 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=13             |            Length=4           |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  | Percentage |     Reserved                   |     Count      |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                Underflow-Threshold-Percentage sub-TLV format

   The Type is 13, 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 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.

PCC reports the calculated bandwidth to be adjusted (MaxAvgBw) to the
PCE using the existing 'Requested Bandwidth' with BANDWIDTH Object-
Type as 1.

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-ATTRIBUTE TLV MUST be included in the LSPA object with the
PCInitiate message.

The definition of the PCInitiate message (see
[I-D.ietf-pce-stateful-pce]) 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-ATTRIBUTE 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 of the PCUpd message (see [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, the BANDWIDTH object of
type 1 is used to specify the requested bandwidth in the PCRpt
message. After the successful delegation, to specify the LSP
bandwidth to be adjusted, the BANDWIDTH object of type 1 is included
in the PCRpt message.

For PCC-Initiated LSPs with Auto-Bandwidth feature enabled, AUTO-
BANDWIDTH-ATTRIBUTE TLV MUST be included in the LSPA object of 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 (PCE or
PCC) SHOULD notify its PCEP peer (PCC or PCE) when it is in
overwhelmed state for 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.

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.

When the PCEP speaker is no longer in the overwhelm state and is
available to process the auto-bandwidth adjustment, 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-ATTRIBUTE 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 tunnel (at
ingress (PCC) 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

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

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

```
Value   Name                                          Reference
----------------------------------------------------------------
TBD2    AUTO-BANDWIDTH-CAPABILITY                     [This I.D.]
TBD1    AUTO-BANDWIDTH-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 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

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

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. New sub-TLV are
allocated only by an IETF Review action [RFC5226].

This document defines the following types:

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

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

8.4. 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
```

8.5. 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 I.D.]

            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.

Contributors' Addresses

   He Zekun
   Tencent Holdings Ltd,
   Shenzhen P.R.China

   EMail: kinghe@tencent.com

   Xian Zhang
   Huawei Technologies
   Research Area F3-1B,
   Huawei Industrial Base,
   Shenzhen, 518129
   China

   Phone: +86-755-28972645
   EMail: zhang.xian@huawei.com

   Young Lee
   Huawei Technologies
   1700 Alma Drive, Suite 100
   Plano, TX 75075
   USA

   Phone: +1 972 509 5599 x2240
   Fax: +1 469 229 5397
   EMail: leeyoung@huawei.com

Authors' Addresses

   Dhruv Dhody
   Huawei Technologies
   Divyashree Techno Park, Whitefield
   Bangalore, Karnataka 560066
   India

   EMail: dhruv.ietf@gmail.com

   Udayasree Palle
   Huawei Technologies
   Divyashree Techno Park, Whitefield
   Bangalore, Karnataka 560037
   India

   EMail: udayasree.palle@huawei.com

   Ravi Singh
   Juniper Networks
   1194 N. Mathilda Ave.
   Sunnyvale, CA 94089
   USA

   EMail: ravis@juniper.net

   Rakesh Gandhi
   Individual Contributor

   EMail: rgandhi.ietf@gmail.com

   Luyuan Fang
   eBay
   USA

   EMail: lufang@ebay.com