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D. Dhody, Ed.
Huawei Technologies
R. Gandhi, Ed.
Cisco Systems, Inc.
U. Palle
R. Singh
Individual Contributor
L. Fang
Expedia, Inc.
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**PCEP Extensions for MPLS-TE LSP Automatic Bandwidth Adjustment with
Stateful PCE
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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.

The automatic bandwidth feature 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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Table of Contents

1.	Introduction	3
2.	Conventions Used in This Document	4
2.1.	Requirements Language	4
2.2.	Abbreviations	4
2.3.	Terminology	5
3.	Requirements for PCEP Extensions	7
4.	Architectural Overview	8
4.1.	Auto-Bandwidth Overview	8
4.2.	Auto-bandwidth Theory of Operation	9
4.3.	Scaling Considerations	10
5.	PCEP Extensions	10
5.1.	Capability Advertisement	10
5.1.1.	AUTO-BANDWIDTH-CAPABILITY TLV	11
5.2.	AUTO-BANDWIDTH-ATTRIBUTES TLV	12
5.2.1.	Sample-Interval sub-TLV	13
5.2.2.	Adjustment Intervals	14
5.2.2.1.	Adjustment-Interval sub-TLV	14
5.2.2.2.	Down-Adjustment-Interval sub-TLV	14
5.2.3.	Adjustment Thresholds	15
5.2.3.1.	Adjustment-Threshold sub-TLV	15
5.2.3.2.	Adjustment-Threshold-Percentage sub-TLV	16
5.2.3.3.	Down-Adjustment-Threshold sub-TLV	17
5.2.3.4.	Down-Adjustment-Threshold-Percentage sub-TLV	18
5.2.4.	Minimum and Maximum Bandwidth Values	19
5.2.4.1.	Minimum-Bandwidth sub-TLV	19
5.2.4.2.	Maximum-Bandwidth sub-TLV	19
5.2.5.	Overflow and Underflow Conditions	20
5.2.5.1.	Overflow-Threshold sub-TLV	20

5.2.5.2.	Overflow-Threshold-Percentage sub-TLV	21
5.2.5.3.	Underflow-Threshold sub-TLV	22
5.2.5.4.	Underflow-Threshold-Percentage sub-TLV	23
5.3.	BANDWIDTH Object	24
5.4.	The PCInitiate Message	24
5.5.	The PCUpd Message	24
5.6.	The PCRpt Message	24
5.7.	The PCNtf Message	25
6.	Manageability Considerations	26
6.1.	Control of Function and Policy	26
6.2.	Information and Data Models	26
6.3.	Liveness Detection and Monitoring	27
6.4.	Verify Correct Operations	27
6.5.	Requirements On Other Protocols	27
6.6.	Impact On Network Operations	27
7.	Security Considerations	28
8.	IANA Considerations	28
8.1.	PCEP TLV Type Indicators	28
8.2.	AUTO-BANDWIDTH-CAPABILITY TLV Flag Field	28
8.3.	AUTO-BANDWIDTH-ATTRIBUTES Sub-TLV	29
8.4.	Error Object	29
8.5.	Notification Object	30
9.	References	31
9.1.	Normative References	31
9.2.	Informative References	31
	Acknowledgments	33
	Contributors' Addresses	33
	Authors' Addresses	34

1. Introduction

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

[RFC8231] 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, [RFC8281] describes the setup, maintenance and teardown of PCE-Initiated LSPs for the stateful PCE model. In this document, the focus is on Active stateful PCE where the LSPs are controlled by the PCE.

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

In the model considered in this document, the PCC (head-end of the LSP) collects the traffic rate samples flowing through the LSP and calculates the new adjusted bandwidth. The PCC reports the calculated bandwidth to be adjusted to the PCE. This is similar to the Passive stateful PCE model: while the Passive stateful PCE uses a path request/reply mechanism, the Active stateful PCE uses a report/update mechanism. 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.

Another approach would be to send the measured values itself to the PCE, which is considered out of scope for this document.

This document defines the PCEP extensions needed to support an Auto-Bandwidth feature in an Active stateful PCE model where the LSP bandwidth to be adjusted is calculated on the PCC (head-end of the LSP). The use of PCE to calculate the bandwidth to be adjusted is out of scope of this document.

[2. Conventions Used in This Document](#)

[2.1. Requirements Language](#)

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [BCP 14](#) [\[RFC2119\]](#) [\[RFC8174\]](#) when, and only when, they appear in all capitals, as shown here.

[2.2. Abbreviations](#)

PCC: Path Computation Client.

PCE: Path Computation Element.

PCEP: Path Computation Element Communication Protocol.

TE LSP: Traffic Engineering Label Switched Path.

2.3. Terminology

The reader is assumed to be familiar with the terminology defined in [\[RFC5440\]](#), [\[RFC8231\]](#), and [\[RFC8281\]](#).

In this document, the PCC is considered to be the head end LSR of the LSP. Other types of PCC are not in scope.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Count. The Underflow-Threshold needs to be greater than or equal to the Down-Adjustment-Threshold.

Minimum-Threshold: When percentage-based thresholds are in use, they are accompanied by this minimum threshold, which is used to enforce that the magnitude of deviation of calculated LSP bandwidth to be adjusted from the current bandwidth reservations exceeds a specific non-percentage-based criterion (represented as an absolute bandwidth value) before any adjustments are made. This serves to suppress unnecessary auto-bandwidth adjustments and re-signaling of the LSP at low bandwidth values.

3. Requirements for PCEP Extensions

The PCEP extensions required for auto-bandwidth are summarized in the following table as well as in Figure 1.

+-----+-----+	
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
LSP Delegation.	LSP Initiation.
+-----+-----+	

Table 1: Requirements for Auto-Bandwidth PCEP extensions

PCE	

	^
AUTO-BANDWIDTH CAPABILITY	AUTO-BANDWIDTH CAPABILITY
AUTO-BANDWIDTH ATTRIBUTES	AUTO-BANDWIDTH ATTRIBUTES
	(For Delegated LSPs)

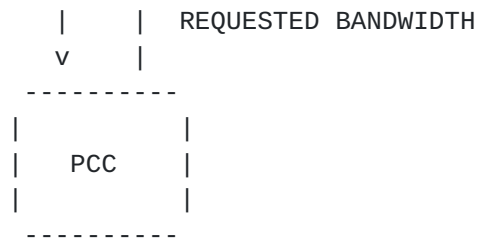


Figure 1: Overview of Auto-Bandwidth PCEP extensions

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

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

- o It is necessary to identify and inform the PCC which LSPs have enabled the Auto-Bandwidth feature. Not all LSPs in some deployments would like their bandwidth to be dependent on the real-time bandwidth usage; for some LSPs leaving the bandwidth constant as set by the operator is preferred.
- o In addition, an operator should be able to specify the auto-bandwidth adjustment parameters (i.e. configuration knobs) to control this feature (e.g. minimum/ maximum bandwidth range). The PCC should be informed about these adjustment parameters.

4. Architectural Overview

4.1. Auto-Bandwidth Overview

The Auto-Bandwidth feature allows automatic and dynamic adjustment of the reserved bandwidth of an LSP over time (i.e., without network operator intervention) to accommodate the varying traffic demand of the LSP. If the traffic flowing through the LSP is lower than the configured or current reserved 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 reserved bandwidth of the LSP, it can potentially cause congestion or packet loss in the network. The initial LSP bandwidth can be set to an arbitrary value (including zero). In practice, it can be set to an expected value based on design and planning. The head-end Label Switch Router (LSR) monitors the actual traffic flowing through the LSP and uses that information to adjust the bandwidth reservation of the LSP in the network.

Bandwidth adjustment must not cause disruption to the traffic flow carried by the LSP. One way to achieve this is to use the make-before-break signaling method [[RFC3209](#)].

4.2. Auto-bandwidth Theory of Operation

This section describes the Auto-Bandwidth feature in a general way. When the Auto-Bandwidth feature is enabled, the measured traffic rate is periodically sampled at each Sample-Interval by the PCC, when the PCC is the head-end node of the LSP. The sample interval can be configured by an operator, with a default value of 5 minutes. A very low Sample-Interval could have some undesirable interactions with transport protocols (see [Section 6.6](#)).

The traffic rate samples are accumulated over the Adjustment-Interval period (in the Up or Down direction). The period can be configured by an operator, with a default value of 24 hours. The PCC in-charge of calculating the bandwidth to be adjusted can decide to adjust the bandwidth of the LSP to the highest traffic rate sample (MaxAvgBw) amongst the set of bandwidth samples collected over the Adjustment-Interval period (in the Up or Down direction) depending on the operator policy.

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

In order to avoid frequent re-signaling, an operator may set a longer adjustment-interval value (Up and/or Down). However, a 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 prematurely expire the adjustment interval and adjust the LSP bandwidth to accommodate the sudden bursts of increase in traffic demand as an overflow condition or decrease in traffic demand as an underflow condition. An operator needs to

configure appropriate values for the Overflow-Threshold and/or Underflow-Threshold parameters and they do not have default values defined in this document.

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

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

4.3. Scaling Considerations

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

If a PCE gets overwhelmed, it can notify the PCC to temporarily suspend the reporting of the new LSP bandwidth to be adjusted (see [Section 5.7](#) of this document). Similarly, if a PCC gets overwhelmed due to signaling churn, it can notify the PCE to temporarily suspend new LSP setup requests (see [Section 5.7](#) of this document).

5. PCEP Extensions

5.1. Capability Advertisement

During PCEP Initialization Phase, PCEP speakers (PCE or PCC) advertise their support of Automatic Bandwidth adjustment feature. A

Advertisement of the AUTO-BANDWIDTH-CAPABILITY TLV implies support of auto-bandwidth adjustment, as well as the objects, TLVs and procedures defined in this document.

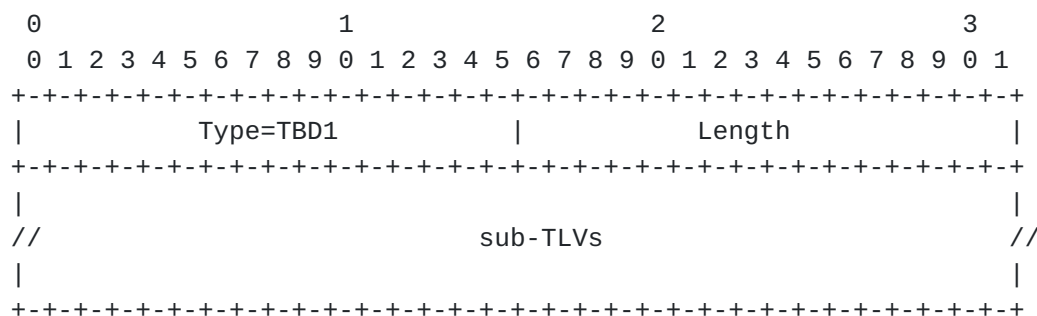
5.2. AUTO-BANDWIDTH-ATTRIBUTES TLV

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

For PCE-Initiated LSP [RFC8281], this TLV is included in the LSPA Object with the PCInitiate message. For the PCC-Initiated delegated LSPs, this TLV is carried in the PCRpt message in LSPA Object. This TLV is also carried in the LSPA object with the PCUpd message to direct the PCC (LSP head-end) to make updates to auto-bandwidth attributes such as Adjustment-Interval.

The TLV is encoded in all PCEP messages for the LSP while the auto-bandwidth adjustment feature is enabled, the absence of the TLV indicates the PCEP speaker wishes to disable the feature. This TLV includes multiple AUTO-BANDWIDTH-ATTRIBUTES sub-TLVs. The AUTO-BANDWIDTH-ATTRIBUTES sub-TLVs are included if there is a change since the last information sent in the PCEP message. The default values for missing sub-TLVs apply for the first PCEP message for the LSP.

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



AUTO-BANDWIDTH-ATTRIBUTES TLV format

Type: TBD1

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

Value: This comprises one or more sub-TLVs.

Following sub-TLVs are defined in this document:

Type Len Name

```

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

```

Future specifications can define additional sub-TLVs.

The sub-TLVs are encoded to inform the PCEP peer of the various sampling and adjustment parameters. In case of a missing sub-TLV, as per the local policy, either the default value (as specified in this document) or some other operator configured value is used.

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

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

5.2.1. Sample-Interval sub-TLV

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

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                               Type=1                               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                               Sample-Interval                       |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Sample-Interval sub-TLV format

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

- o Sample-Interval: The 4-octet time interval for bandwidth sample collection. The valid range is from 1 to 604800 (7 days), in seconds. The default value is 300 seconds. Due care needs to be

taken in case of a very low Sample-Interval, as it can have some undesirable interactions with transport protocols (see [Section 6.6](#)). The sample-interval parameter MUST NOT be greater than the (down) adjustment-interval. In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.2. Adjustment Intervals

The sub-TLVs in this section are encoded to inform the PCEP peer the adjustment interval parameters. The Adjustment-Interval sub-TLV specifies the time interval for both upward (Up-Adjustment-Interval) and downward (Down-Adjustment-Interval) trends. An implementation MAY require to set a different adjustment interval values for when the bandwidth usage trend is downwards from when it is moving upwards. In that case, the operator could use the Down-Adjustment-Interval sub-TLV which overrides the Adjustment-Interval value for Down-Adjustment-Interval.

5.2.2.1. Adjustment-Interval sub-TLV

The Adjustment-Interval sub-TLV specifies a time interval in seconds at which bandwidth adjustment should be made in upward or downward direction. This sub-TLV specify the value for Up-Adjustment-Interval and Down-Adjustment-Interval when they are the same and the Down-Adjustment-Interval sub-TLV is not included.

```

0           1           2           3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Type=2           |           Length=4           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Adjustment-Interval           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Adjustment-Interval sub-TLV format

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

- o Adjustment-Interval: The 4-octet time interval for bandwidth adjustments. The valid range is from 1 to 604800 (7 days), in seconds. The default value is 86400 seconds (1 day). The adjustment-interval parameter MUST NOT be less than the sample-interval, otherwise the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.2.2. Down-Adjustment-Interval sub-TLV

The Down-Adjustment-Interval sub-TLV specifies a time interval in

seconds at which bandwidth adjustment should be made when MaxAvgBw is less than the current bandwidth reservation of the LSP. This parameter overrides the Adjustment-Interval for the downward trend. This sub-TLV is used only when there is a need for different adjustment intervals in the upward and downward directions.

```

      0               1               2               3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|               Type=3               |               Length=4               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|               Down-Adjustment-Interval               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Down-Adjustment-Interval sub-TLV format

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

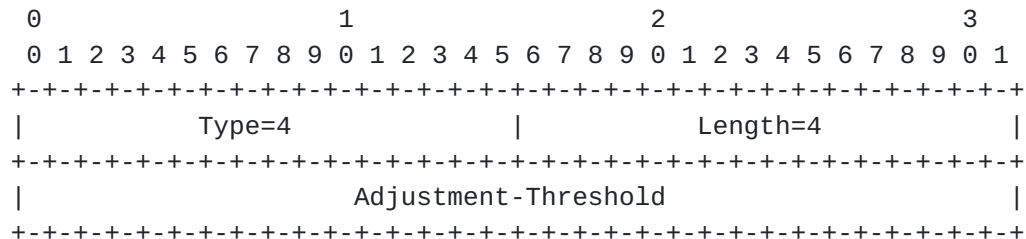
- o Down-Adjustment-Interval: The 4-octet time interval for downward bandwidth adjustments. The valid range is from 1 to 604800 (7 days), in seconds. The default value equals the adjustment-interval. The down-adjustment-interval parameter MUST NOT be less than the sample-interval, otherwise the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.3. Adjustment Thresholds

The sub-TLVs in this section are encoded to inform the PCEP peer of the adjustment threshold parameters. An implementation MAY include both sub-TLVs for the absolute value and the percentage, in which case the bandwidth is adjusted when either of the adjustment threshold conditions are met. The Adjustment-Threshold sub-TLV specifies the threshold for both upward (Up-Adjustment-Threshold) and downward (Down-Adjustment-Threshold) trend. If the operator would like to use a different adjustment threshold during the downward trend, the Down-Adjustment-Threshold sub-TLV is included. Similarly, the Adjustment-Threshold-Percentage sub-TLV specifies the threshold percentage for both upward and downward trend. If the operator would like to use a different adjustment threshold percentage during the downward trend, the Down-Adjustment-Threshold-Percentage sub-TLV is included. It is worth noting that regardless of how the threshold are set, the adjustment will not be made until at least one sample-interval simply because no sample will be made on which to base a comparison with a threshold.

5.2.3.1. Adjustment-Threshold sub-TLV

The Adjustment-Threshold sub-TLV is used to decide when the LSP bandwidth should be adjusted in upward or downward direction. This sub-TLV specify the absolute value for Up-Adjustment-Threshold and Down-Adjustment-Threshold when they are the same and the Down-Adjustment-Threshold sub-TLV is not included.



Adjustment-Threshold sub-TLV format

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

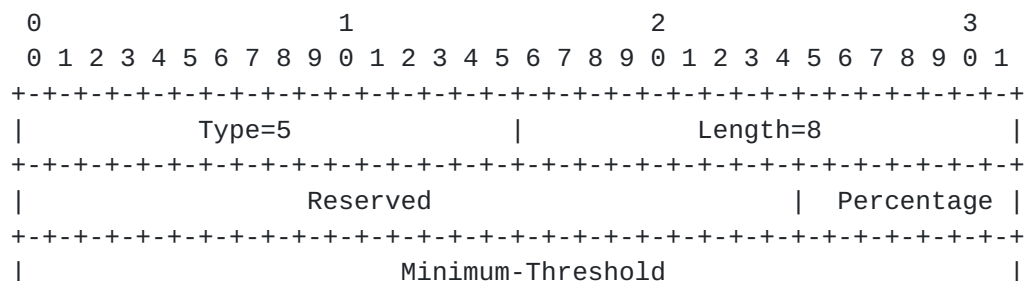
- o Adjustment-Threshold: The absolute Adjustment-Threshold bandwidth difference value, encoded in IEEE floating point format (see [\[IEEE.754.1985\]](#)), expressed in bytes per second. The default adjustment-threshold value is not set. Refer to [Section 3.1.2 of \[RFC3471\]](#) for a table of commonly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

If the modulus of 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).

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

[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 in upward or downward direction. This sub-TLV specify the percentage value for Up-Adjustment-Threshold and Down-Adjustment-Threshold when they are the same and the Down-Adjustment-Threshold-Percentage sub-TLV is not included.




```

+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Adjustment-Threshold-Percentage sub-TLV format

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

- o Reserved: MUST be set to zero on transmission and MUST be ignored on receipt.
- o Percentage: The Adjustment-Threshold value (7 bits), encoded in percentage (an integer from 1 to 100). The value 0 is considered to be invalid. The default value is 5 percent.
- o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value, encoded in IEEE floating point format (see [[IEEE.754.1985](#)]), expressed in bytes per second. The increase or decrease of the LSP bandwidth MUST be at least or above the minimum-threshold before the bandwidth adjustment is made. The default value is 0.

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

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.3.3. Down-Adjustment-Threshold sub-TLV

The Down-Adjustment-Threshold sub-TLV is used to decide when the LSP bandwidth should be adjusted when MaxAvgBw is lesser than the current bandwidth reservation. This parameter overrides the Adjustment-Threshold for the downward trend. This sub-TLV is used only when there is a need for different threshold in the upward and downward directions.

```

      0               1               2               3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|               Type=6               |               Length=4               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|               Down-Adjustment-Threshold               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Down-Adjustment-Threshold sub-TLV format

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

- 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

[illegible]

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

- o Reserved: MUST be set to zero on transmission and MUST be ignored on receipt.
- o Percentage: The Down-Adjustment-Threshold value (7 bits), encoded in percentage (an integer from 1 to 100). The value 0 is considered to be invalid. The default value equals the adjustment-threshold-percentage.
- o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value, encoded in IEEE floating point format (see [[IEEE.754.1985](#)]), expressed in bytes per second. The decrease of the LSP bandwidth MUST be at least or above the minimum-threshold before the

bandwidth adjustment is made. The default value equals the minimum-threshold for the adjustment-threshold-percentage.

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

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.4. Minimum and Maximum Bandwidth Values

5.2.4.1. Minimum-Bandwidth sub-TLV

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

```

      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                               |                               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                               |                               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Minimum-Bandwidth sub-TLV format

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

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

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.4.2. Maximum-Bandwidth sub-TLV

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

```

      0                   1                   2                   3

```



```

 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Type=9           |           Length=4           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Maximum-Bandwidth           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Maximum-Bandwidth sub-TLV format

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

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

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.5. Overflow and Underflow Conditions

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

5.2.5.1. Overflow-Threshold sub-TLV

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

```

 0                               1                               2                               3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Type=10           |           Length=8           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Reserved           |           Count           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|           Overflow-Threshold           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Overflow-Threshold sub-TLV format

- o Reserved: MUST be set to zero on transmission and MUST be ignored on receipt.
- o Count: The Overflow-Count value (5 bits), encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the (up) adjustment-interval.
- o Overflow-Threshold: The absolute Overflow-Threshold bandwidth value, encoded in IEEE floating point format (see [\[IEEE.754.1985\]](#)), expressed in bytes per second. Refer to [Section 3.1.2 of \[RFC3471\]](#) for a table of commonly used values. If the difference 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

[illegible]

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

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

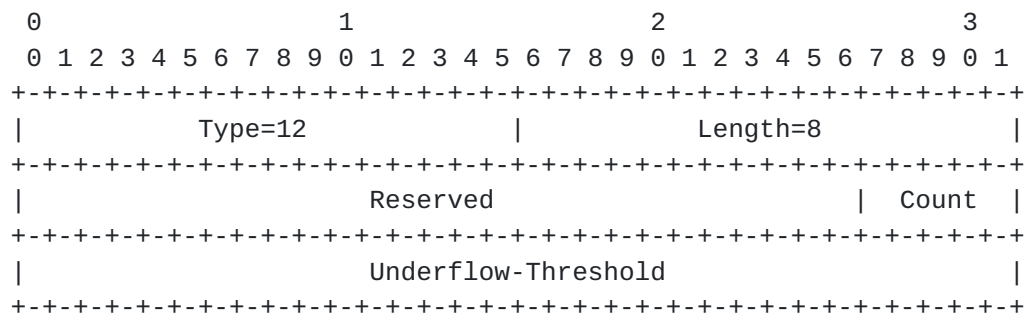
on receipt.

- o Count: The Overflow-Count value (5 bits), encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the overflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the (up) adjustment-interval.
- o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value, encoded in IEEE floating point format (see [[IEEE.754.1985](#)]), expressed in bytes per second. The increase of the LSP bandwidth MUST be at least or above the minimum-threshold before the bandwidth adjustment is made.

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.5.3. Underflow-Threshold sub-TLV

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



Underflow-Threshold sub-TLV format

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

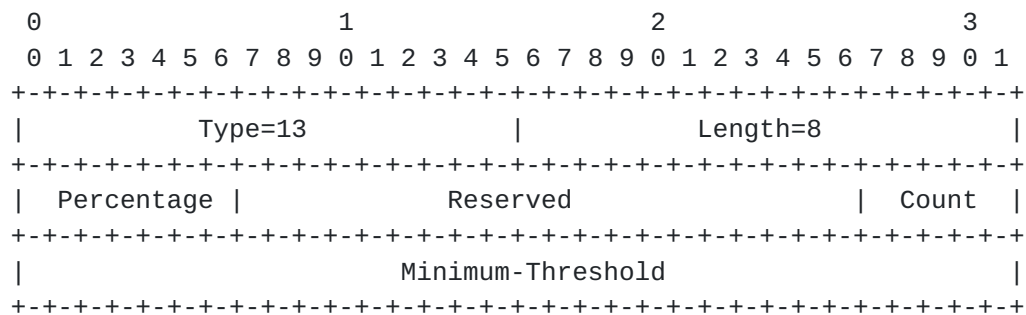
- o Reserved: MUST be set to zero on transmission and MUST be ignored on receipt.
- o Count: The Underflow-Count value (5 bits), encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the underflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the down-adjustment-interval.
- o Underflow-Threshold: The absolute Underflow-Threshold bandwidth value, encoded in IEEE floating point format (see [IEEE.754.1985]), expressed in bytes per second. Refer to Section

3.1.2 of [[RFC3471](#)] for a table of commonly used values. If the difference of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold value, the underflow condition is met.

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.2.5.4. Underflow-Threshold-Percentage sub-TLV

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



Underflow-Threshold-Percentage sub-TLV format

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

- o Percentage: The Underflow-Threshold value (7 bits), encoded in percentage (an integer from 1 to 100). The value 0 is considered to be invalid. If the percentage decrease of the current MaxAvgBw from the current bandwidth reservation is greater than or equal to the threshold percentage, the underflow condition is met.
- o Reserved: MUST be set to zero on transmission and MUST be ignored on receipt.
- o Count: The Underflow-Count value (5 bits), encoded in integer. The value 0 is considered to be invalid. The number of consecutive samples for which the underflow condition MUST be met for the LSP bandwidth to be immediately adjusted to the current bandwidth demand, bypassing the down-adjustment-interval.
- o Minimum-Threshold: The absolute Minimum-Threshold bandwidth value, encoded in IEEE floating point format (see [[IEEE.754.1985](#)]), expressed in bytes per second. The decrease of the LSP bandwidth MUST be at least or above the minimum-threshold before the bandwidth adjustment is made.

In case of an invalid value, the Sub-TLV MUST be ignored and the previous value is maintained.

5.3. BANDWIDTH Object

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

- o Requested Bandwidth: BANDWIDTH Object-Type value is 1.
- o Re-optimization Bandwidth: Bandwidth of an existing TE LSP for which a re-optimization is requested. BANDWIDTH Object-Type value is 2.

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

5.4. The PCInitiate Message

A PCInitiate message is a PCEP message sent by a PCE to a PCC to trigger LSP instantiation or deletion [\[RFC8281\]](#).

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

The Routing Backus-Naur Format (RBNF) definition of the PCInitiate message [\[RFC8281\]](#) 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 [\[RFC8231\]](#).

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

The RBNF definition of the PCUpd message [\[RFC8231\]](#) is unchanged by this document.

5.6. The PCRpt Message

The PCRpt message [\[RFC8231\]](#) is a PCEP message sent by a PCC to a PCE

to report the status of one or more LSPs.

For PCE-Initiated LSPs [[RFC8281](#)], the PCC creates the LSP using the attributes communicated by the PCE, and using the local values for the unspecified parameters. After the successful instantiation of the LSP, PCC automatically delegates the LSP to the PCE and generates a PCRpt message to provide the status report for the LSP.

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

The RBNF definition of the PCRpt message [[RFC8231](#)] is unchanged by this document.

5.7. The PCNtf Message

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

A PCEP speaker (PCE or PCC) SHOULD notify its PCEP peer (PCC or PCE) when it is in overwhelmed state due to the auto-bandwidth feature. An implementation needs to make an attempt to send this notification (when overwhelmed by auto-bandwidth adjustments) unless sending this notification would only serve to increase the load further. Note that when the notification is not received the PCEP speaker would continue to request bandwidth adjustments even when they could not be handled in a timely fashion.

Upon receipt of auto-bandwidth overwhelm notification, the peer SHOULD NOT send any PCEP messages related to auto-bandwidth adjustment. If a PCEP message related to auto-bandwidth adjustment is received during in overwhelmed state, it MUST be ignored.

- o When a PCEP speaker is overwhelmed, it SHOULD notify its peer by sending a PCNtf message with Notification-Type = TBD3 (Auto-bandwidth Overwhelm State) and Notification-Value = 1 (Entering auto-bandwidth overwhelm state). Optionally, OVERLOADED-DURATION TLV [[RFC5440](#)] MAY be included that specifies the time period during which no further PCEP messages related to auto-bandwidth adjustment should be sent.
- o When the PCEP speaker is no longer in the overwhelm state and is available to process the auto-bandwidth adjustments, it SHOULD notify its peers by sending a PCNtf message with Notification Type = TBD3 (Auto-bandwidth Overwhelm State) and Notification Value = 2 (Clearing auto-bandwidth overwhelm state). A PCEP speaker SHOULD

send such notification to all peers to with a Notification message (Notification-Type=TBD3, Notification-Value=1) was sent earlier unless an OVERLOADED-DURATION TLV was included and the PCEP speakers wishes for the peer to wait for the expiration of that period of time before receiving further PCEP messages related to auto-bandwidth adjustment.

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.

Some dampening notification procedure (as per [[RFC5440](#)]) to avoid oscillations of the overwhelm state is RECOMMENDED. On receipt of an auto-bandwidth overwhelm notification from the PCE, a PCC should consider the impact on the entire network. Moving the delegations of auto-bandwidth enabled LSP to another PCE could cause further overloading.

6. Manageability Considerations

6.1. Control of Function and Policy

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

The Maximum-Bandwidth (and Minimum-Bandwidth) should be set to acceptable limit to avoid impact on the rest of the MPLS-TE domain.

The operator should make sure that the Overflow-Threshold is greater than or at least equal to the Up-Adjustment-Threshold. And similarly, make sure that the Underflow-Threshold is greater than or at least equal to the Down-Adjustment-Threshold.

6.2. Information and Data Models

A MIB module for gathering operational information about PCEP is defined in [[RFC7420](#)]. Additionally, the YANG module defined in [[I-D.ietf-pce-pcep-yang](#)] provides for both configuration of PCEP as well as operational management. These could 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

could be added.

6.3. Liveness Detection and Monitoring

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

6.4. Verify Correct Operations

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

In case of an invalid value, the Sub-TLV would get ignored and the previous value would be maintained. In such case the implementation SHOULD log the event.

6.5. Requirements On Other Protocols

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

6.6. 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. For each LSP enabled with auto-bandwidth feature there is an extra load on PCC, as it needs to monitor the traffic and report the calculated bandwidth to be adjusted to the PCE. The PCE further re-compute paths based on the requested bandwidth and update the path to the PCC, which in turns triggers the re-signaling of the path. All these steps adds extra load and churn in the network and thus operator needs to take due care while enabling this features on a number of LSPs.

An implementation MAY allow a limit to be placed on the rate of auto-bandwidth related messages sent by a PCEP speaker and received by a peer. An implementation SHOULD also allow sending a notification when a PCEP speaker is overwhelmed or the rate of messages reach a threshold.

Due care is required by the operator if a Sample-Interval value significantly smaller than the default (5 minute) is used, as a small Sample-Interval values, e.g., 1 minute or less, could cause undesirable interactions with transport protocols. These undesirable interactions result from providing insufficient time for transport protocol reactions to a prior bandwidth adjustment to settle out

before bandwidth samples are taken for the next bandwidth adjustment.

7. Security Considerations

This document defines AUTO-BANDWIDTH-CAPABILITY TLV and AUTO-BANDWIDTH-ATTRIBUTES sub-TLVs which do not add any substantial new security concerns beyond those already discussed in [\[RFC8231\]](#) and [\[RFC8281\]](#) for stateful PCE operations. As per [\[RFC8231\]](#), it is RECOMMENDED that these PCEP extensions only be activated on authenticated and encrypted sessions across PCEs and PCCs belonging to the same administrative authority, using Transport Layer Security (TLS) [\[RFC8253\]](#), as per the recommendations and best current practices in [BCP 195](#) [\[RFC7525\]](#) (unless explicitly set aside in [\[RFC8253\]](#)).

Incorrect auto-bandwidth parameters in the AUTO-BANDWIDTH-ATTRIBUTES sub-TLVs could have an adverse effect on the LSP as well as on the network.

8. IANA Considerations

8.1. PCEP TLV Type Indicators

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

Value	Name	Reference

TBD2	AUTO-BANDWIDTH-CAPABILITY	[This document]
TBD1	AUTO-BANDWIDTH-ATTRIBUTES	[This document]

8.2. AUTO-BANDWIDTH-CAPABILITY TLV Flag Field

IANA is requested to create a sub-registry to manage the Flag field of the AUTO-BANDWIDTH-CAPABILITY TLV within the "Path Computation Element Protocol (PCEP) Numbers" registry.

New bit numbers are to be assigned by Standards Action [\[RFC8126\]](#). Each bit should be tracked with the following qualities:

- o Bit number (counting from bit 0 as the most significant bit)
- o Capability description
- o Defining RFC

The initial contents of the sub-registry are empty, with all bits

marked unassigned

8.3. AUTO-BANDWIDTH-ATTRIBUTES Sub-TLV

This document specifies the AUTO-BANDWIDTH-ATTRIBUTES Sub-TLVs. IANA is requested to create an "AUTO-BANDWIDTH-ATTRIBUTES Sub-TLV Types" sub-registry within the "Path Computation Element Protocol (PCEP) Numbers" registry to manage the type indicator space for sub-TLVs of the AUTO-BANDWIDTH-ATTRIBUTES TLV. The valid range of values in the registry is 0-65535. IANA is requested to initialize the registry with the following values. All other values in the registry should be marked as "Unassigned".

IANA is requested to set the registration procedure for this registry to read as follows:

0-65503	IETF Review
65504-65535	Experimental Use

This document defines the following types:

Type	Name	Reference
0	Reserved	[This document]
1	Sample-Interval sub-TLV	[This document]
2	Adjustment-Interval sub-TLV	[This document]
3	Down-Adjustment-Interval sub-TLV	[This document]
4	Adjustment-Threshold sub-TLV	[This document]
5	Adjustment-Threshold-Percentage sub-TLV	[This document]
6	Down-Adjustment-Threshold sub-TLV	[This document]
7	Down-Adjustment-Threshold-Percentage sub-TLV	[This document]
8	Minimum-Bandwidth sub-TLV	[This document]
9	Maximum-Bandwidth sub-TLV	[This document]
10	Overflow-Threshold sub-TLV	[This document]
11	Overflow-Threshold-Percentage sub-TLV	[This document]
12	Underflow-Threshold sub-TLV	[This document]
13	Underflow-Threshold-Percentage sub-TLV	[This document]
14-65503	Unassigned	[This document]

8.4. Error Object

This document defines a new Error-Value for PCErr message of Error-Type 19 (Invalid Operation) [[RFC8231](#)]. IANA is requested to allocate new error-value within the "PCEP-ERROR Object Error Types and Values" subregistry of the PCEP Numbers registry, as follows:

Error-Type	Meaning & error values	Reference
------------	------------------------	-----------

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

8.5. Notification Object

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

Type	Meaning	Reference
-----	-----	-----
TBD3	Auto-Bandwidth Overwhelm State	[This document]
	Notification-value=1:	Entering Auto-Bandwidth overwhelm state
	Notification-value=2:	Clearing Auto-Bandwidth overwhelm state

9. References

9.1. Normative References

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- [RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", [BCP 26](#), [RFC 8126](#), DOI 10.17487/RFC8126, June 2017, <<https://www.rfc-editor.org/info/rfc8126>>.
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- [RFC8253] Lopez, D., Dios, O., Wu, W., and D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", [RFC 8253](#), October 2017, <<https://www.rfc-editor.org/info/rfc8253>>.
- [RFC8281] Crabbe, E., Minei, I., Sivabalan, S., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for PCE-Initiated LSP Setup in a Stateful PCE, Model", [RFC 8281](#), DOI 10.17487/RFC8281, December 2017, <<https://www.rfc-editor.org/info/rfc8281>>.
- [IEEE.754.1985] Institute of Electrical and Electronics Engineers, "Standard for Binary Floating-Point Arithmetic", IEEE Standard 754, August 1985.

9.2. Informative References

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

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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
SKKU

Email: younglee.tx@gmail.com

Authors' Addresses

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

Email: dhruv.ietf@gmail.com

Rakesh Gandhi (editor)
Cisco Systems, Inc.
Canada

Email: rgandhi@cisco.com

Udayasree Palle
Individual Contributor

Email: udayasreereddy@gmail.com

Ravi Singh
Individual Contributor

Email: ravi.singh.ietf@gmail.com

Luyuan Fang
Expedia, Inc.
USA

Email: luyuanf@gmail.com

