PCE Working Group
Internet-Draft
Intended status: Standards Track
Expires: 24 October 2026

R. Gandhi
Cisco Systems, Inc.
B. Wen
Comcast
C. Barth
HPE
D. Dhody
Huawei Technologies
A. Stone
Nokia

22 April 2026

# PCEP Extensions for Performance Measurement for SR-TE and MPLS-TE LSPs with Stateful PCE
draft-gandhi-pce-pm-12

## Abstract

In certain networks, network performance data such as packet loss, delay, and delay variation, as well as bandwidth utilization, are critical measures for Traffic Engineering (TE). These data provide operators with the characteristics of their networks for the performance evaluation required to provide Service-Level Agreements (SLAs).

Stateful Path Computation Element Communication Protocol (PCEP) extensions have been defined for TE LSPs for Segment Routing (SR) and RSVP. This document describes the PCEP extensions for enabling and reporting end-to-end performance measurement and liveness detection for both PCE-Initiated and PCC-Initiated LSPs for SR-TE over MPLS and IPv6 data planes, and MPLS-TE using RSVP to an Active Stateful PCE.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 24 October 2026.



Table of Contents

## 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 Traffic Engineering Label Switched Paths (TE LSPs).

[RFC8231] specifies extensions to PCEP to enable stateful control of an LSP. It describes two modes of operation - 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 the Active Stateful PCE where the LSPs are controlled by the PCE, for both PCE-Initiated and PCC-Initiated LSPs.

PCEP Extensions for Segment Routing (SR) [RFC8664] specifies extensions to the Path Computation Element Protocol (PCEP) that allow a stateful PCE to compute and initiate Traffic Engineering (TE) paths, as well as a PCC to request a path subject to certain constraints and optimization criteria for Segment Routing. [RFC9603] extends PCEP for Segment Routing for the IPv6 data plane.

In certain networks, such as financial information networks, network performance data such as packet loss, delay, and delay variation, and bandwidth utilization are critical measures for traffic engineering. The protocol extensions have been defined to advertise link performance metrics; see [RFC7471], [RFC8570], [RFC7823] and [RFC8571]. These data provide operators with the characteristics of their networks for performance evaluation that is required to ensure the Service-Level Agreements (SLAs).

[RFC8233] defines the PCEP extensions for LSP path computation using packet loss, delay, and delay variation as path selection metrics. Such path computations use link metrics for packet loss and delay and do not provide end-to-end metrics of the TE LSPs. The end-to-end metrics of an LSP may be very different from the path computation results due to many factors, such as queuing, etc. There is a need to monitor whether the traffic sent over the established LSPs exceeds the requested metric bounds such as end-to-end delay and loss. The Stateful PCE may need to take some action (such as tearing down or re-optimizing the LSP) when the performance requirement is not met. [RFC8762] defines protocol extensions needed for measuring packet loss, delay, and delay variation and can be used for end-to-end performance measurement of an LSP.

This document describes PCEP extensions for enabling and reporting end-to-end performance measurement (PM) such as packet loss, delay, delay variation, bandwidth utilization, as well as liveness detection for both PCE-Initiated and PCC-Initiated LSPs for SR-TE over MPLS and IPv6 data planes and MPLS-TE using RSVP to an Active Stateful PCE.

Note that the specification of the use of the reported packet loss, delay, and delay variation measurements, bandwidth utilization, and liveness detection by a Stateful PCE is outside the scope of this document.

### 1.1. Auto-bandwidth Considerations

The auto-bandwidth feature allows a head-end LSR PCC to automatically adjust the LSP bandwidth reservation based on the traffic demand of an LSP. The auto-bandwidth requested bandwidth computation can be implemented on a PCC or a Stateful PCE.

[RFC8733] describes the PCEP extensions for auto-bandwidth, where the requested bandwidth for the LSP is computed by the PCC and reported to the Stateful PCE. There is a benefit in pushing the responsibility for deciding when auto-bandwidth adjustments are needed to the PCC as this distributes the load of monitoring the bandwidth utilization of the LSPs down to the PCCs and frees up the PCE for path computations. In addition, it reduces the load on PCEP communications for reporting the bandwidth utilization of the LSP.

However, exactly when to adjust an LSP bandwidth could be better left to a Stateful PCE. That is, a PCE could be flexible in its interpretation of thresholds enabling it to trigger auto-bandwidth adjustment early if it believes there is a good reason (for example, performing a set of parallel path recomputations) or late (for example, when it knows that an adjustment would be disruptive to the network). When the auto-bandwidth computation is delegated to the

PCC, the PCC cannot see the impact on other LSPs in the network, and the PCE cannot tell whether the request to adjust the LSP bandwidth is critical or not. The bandwidth utilization reporting defined in this document can be used by the PCE to do computations to determine whether auto-bandwidth adjustments are needed or desirable before performing the path computations.

## 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. Terminology

The reader is assumed to be familiar with the terminology defined in [RFC5440], [RFC8231], [RFC8281], [RFC8408], and [RFC7471].

This document extends the following term defined in [RFC3031]: Label Switched Path (LSP), while the base PCEP specification [RFC4655] originally defined the PCE architecture for MPLS and GMPLS networks with LSPs instantiated using the RSVP-TE signaling protocol. As specified in the Terminology Section of [RFC9603], the term "LSP" used in the PCEP specifications would be equivalent to an SRv6 path (represented as a list of SRv6 segments) in the context of supporting SRv6 in PCEP using the SRv6 Path Setup Type.

### 2.3. Measurement Units

The measurement unit for the delay value is defined in [RFC7471], Section 4.1.5.

The measurement unit for the loss value is defined in [RFC7471], Section 4.4.5.

The utilized bandwidth [RFC7471] is encoded in IEEE floating-point format in bytes per second as described in [IEEE.754.1985].

All average values are calculated as rolling averages.

## 3. Overview of the PCEP Extensions

The high-level overview of the PCEP extensions defined in this document for requesting and reporting end-to-end performance measurement, bandwidth utilization, and liveness detection of the LSPs for SR-TE over MPLS and IPv6 data planes as well as MPLS-TE using RSVP is shown in Figure 1.

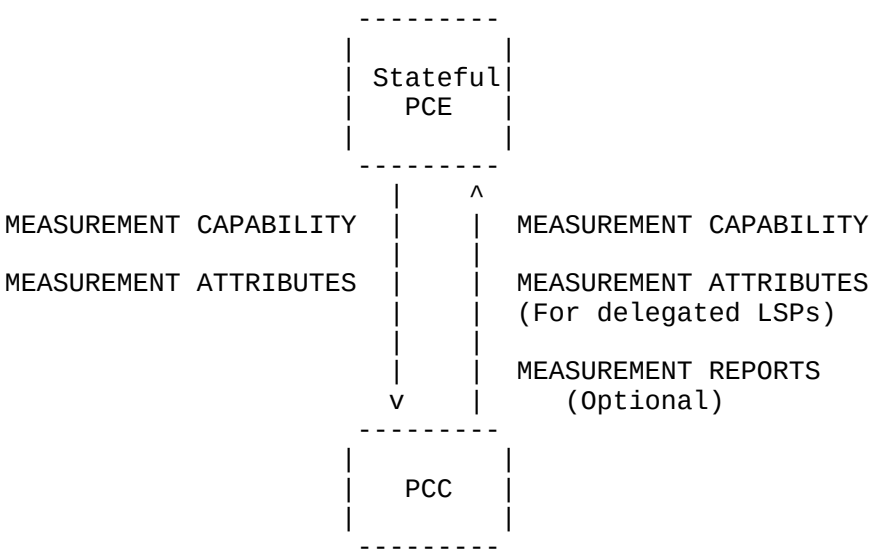


Figure 1: Overview of the PCEP Extensions

The following list provides the high-level overview of the PCEP extensions defined in this document:

* The Stateful PCE and PCC (head-end of the LSP) advertise the capability of their support for the delay and loss measurements, bandwidth-utilization, and liveness detection in the PCEP Open message (in the OPEN Object).

* The Stateful PCE enables measurement of a feature and sends or updates the attributes of the feature using the LSPA object to the PCC in PCInitiate and PCUpd messages, respectively.

* The PCC reports the measured metrics of the feature to the Stateful PCE at the end of the specified interval or when measured values cross a specified threshold. Periodic reporting can be used by the PCE to monitor the LSP metrics, whereas a threshold can be used to trigger an immediate action by the PCE on the LSP.

* The optional periodic reporting of the measurements may be disabled to avoid processing load on the PCE and only an upper bound threshold is used to detect an anomaly, which when exceeded, a local or PCE-set action may be taken on the PCC.

* The PCE and PCC notify each other of their entering and clearing the overwhelmed state when operating under high LSP scale.

### 3.1. Report Thresholds

When explicitly configured, a report threshold (absolute or percentage) parameter is used to trigger an immediate reporting of the delay and loss metrics and bandwidth utilization, bypassing the periodic report interval. A threshold is used to detect a sudden change in the performance measurement metric of an LSP. In order to detect that a measured value has crossed the threshold, the measured (delay/loss) metric is compared with the previously reported value. If the change (increase or decrease) in the value is above the threshold (absolute or percentage), the measurement from the current interval is reported immediately.

All thresholds in this document could be represented in both absolute values and percentages, and could be used together. This is provided to accommodate the cases where the metric values may become very large or very small over time. For example, an operator may use the percentage threshold to handle small to large metric values and absolute values to handle very large metric values. The metrics are reported when either one of the two thresholds, the absolute or the percentage, is crossed.

When using the percentage threshold, if the metric changes rapidly at very low values, it may trigger frequent reporting due to the crossing of the percentage threshold. This can lead to unnecessary scale issues in the network. This is suppressed by setting the minimum-threshold parameter along with the percentage threshold. The metric value is only reported if the value crosses both the percentage threshold and the minimum-threshold parameters.

The metrics are still reported at the end of the report interval even if they were reported due to the threshold crossing. Refer to [RFC7471], Section 5, for additional considerations.

## 4. Sub-TLVs for Measurement Attributes

This section specifies the generic sub-TLVs that provide various configurable parameters for reporting measurement to a Stateful PCE. These sub-TLVs are carried in various measurement attributes TLVs defined in this document.

The following sub-TLVs are defined:

| Type | Length | Name |
|---|---|---|
| 1 | 4 | Measurement-Enable sub-TLV |
| 2 | 4 | Transmit-Interval sub-TLV |
| 3 | 8 | Measurement-Protocol sub-TLV |
| 4 | 4 | Measurement-Interval sub-TLV |
| 5 | 8 | Report-Threshold sub-TLV |
| 6 | 8 | Report-Threshold-Percentage sub-TLV |
| 7 | 4 | Report-Interval sub-TLV |
| 8 | 8 | Report-Upper-Lower-Bound sub-TLV |

The Measurement-Enable sub-TLV MUST be added to the LSPA Object when the measurement feature is enabled for the LSP. All other sub-TLVs are optional and any unrecognized sub-TLV MUST be silently 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. If sub-TLVs are not present, the default values based on the local policy are assumed.

## 4.1. Measurement-Enable sub-TLV

The Measurement-Enable sub-TLV specifies that the given measurement feature is enabled. The format of this sub-TLV is shown in Figure 2.

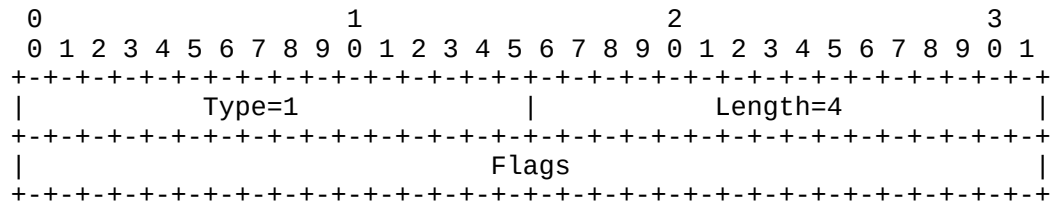


Figure 2: Measurement-Enable sub-TLV Format

The Type is 1, Length is 4 bytes, and the value comprises flags (32 bits) for enabling various measurement features.

Unassigned flags are considered reserved, they MUST be set to 0 when sent and MUST be ignored when received. The flags define various performance measurement types in this document.

## 4.2. Transmit-Interval sub-TLV

The Transmit-Interval sub-TLV specifies a time interval in milliseconds for the test packet transmission. The format of this sub-TLV is shown in Figure 3.

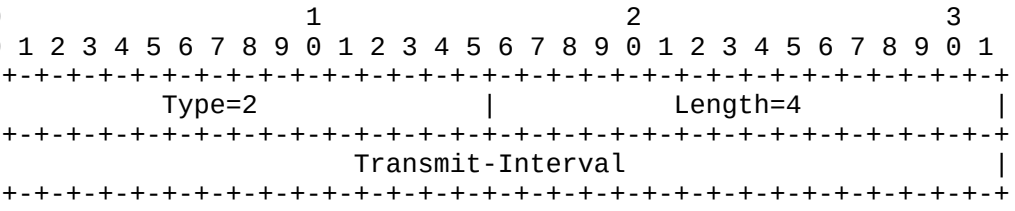


Figure 3: Transmit-Interval sub-TLV Format

The Type is 2, Length is 4 bytes, and the value comprises a 4-byte time interval, the valid range is from 1 to 604800, in milliseconds. The default value is 1 second. The Transmit-Interval MUST NOT be greater than the Measurement-Interval and the Report-Interval.

### 4.3. Measurement-Protocol sub-TLV

The Measurement-Protocol sub-TLV specifies that the given measurement protocol type and mode are enabled. The format of this sub-TLV is shown in Figure 4.

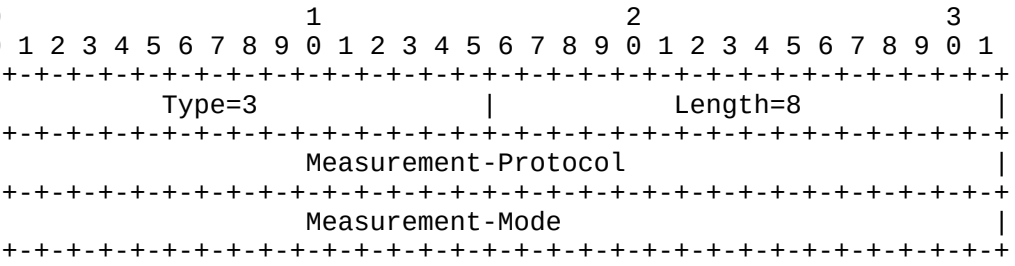


Figure 4: Measurement-Protocol sub-TLV Format

The Type is 3, Length is 8 bytes, and the value comprises the protocol type and mode for performance measurement.

The measurement protocol type value can be set to: (1) STAMP protocol [RFC8762], or (2) TWAMP protocol [RFC5357], or (3) MPLS-PM protocol [RFC6374].

Measurement mode can be set to: (1) One-Way, or (2) Two-Way, or (3) Loopback.

The performance measurement procedures using STAMP defined in [I-D.ietf-spring-stamp-srpm-srv6] and [I-D.ietf-spring-stamp-srpm-mpls] can be used for SR LSPs for the IPv6 and MPLS data planes, respectively. Similarly, the performance measurement procedures using MPLS-PM defined in [RFC9779] can be used for MPLS LSPs.

### 4.4. Measurement-Interval sub-TLV

The Measurement-Interval sub-TLV specifies a time interval in seconds for the measurement. The format of this sub-TLV is shown in Figure 5.

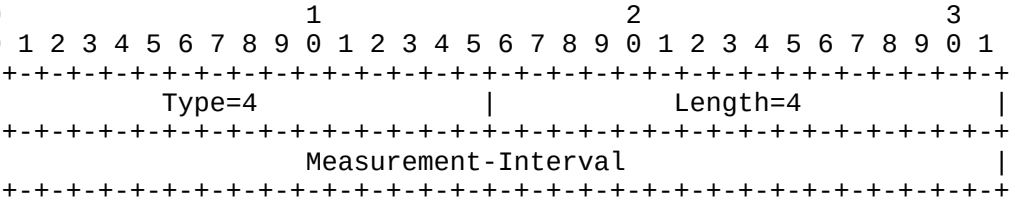


Figure 5: Measurement-Interval sub-TLV Format

The Type is 4, Length is 4 bytes, and the value comprises a 4-byte time interval, the valid range is from 1 to 604800, in seconds. The default value is 300 seconds. The Measurement-Interval MUST NOT be greater than the Report-Interval.

### 4.5. Report-Threshold sub-TLV

The Report-Threshold sub-TLV specifies the threshold value used to trigger an immediate reporting of the measurements bypassing the report-interval. The format of this sub-TLV is shown in Figure 6.

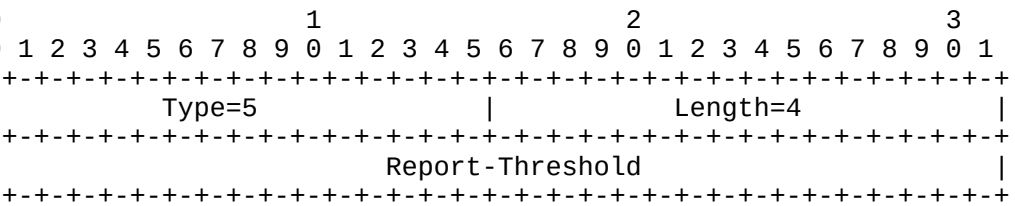


Figure 6: Report-Threshold sub-TLV Format

The Type is 5, Length is 8 bytes, and the value comprises:

* Report-Threshold: 32-bit absolute threshold value. By default, report-threshold is not set and threshold check based reporting is disabled.

## 4.6. Report-Threshold-Percentage sub-TLV

The Report-Threshold-Percentage sub-TLV specifies the threshold value used to trigger an immediate reporting of the measurements bypassing the report-interval. The format of this sub-TLV is shown in Figure 7.

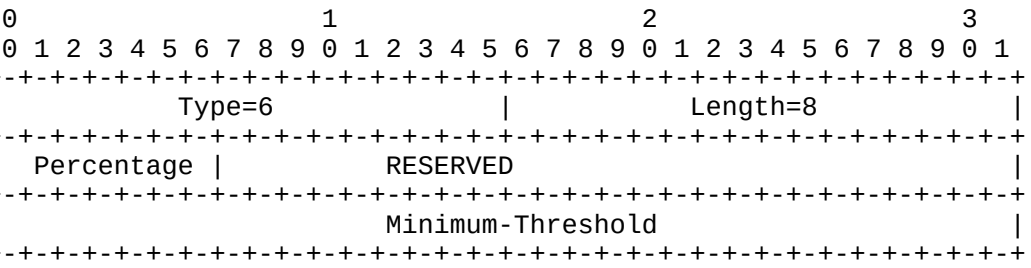


Figure 7: Report-Threshold-Percentage sub-TLV Format

The Type is 6, Length is 8 bytes, and the value comprises:

* Percentage: 7-bit threshold value, encoded in percentage as an integer from 1 to 100.

  By default, report-threshold-percentage is not set and threshold check based reporting is disabled.

* RESERVED: It MUST be set to zero when sent and MUST be ignored when received.

* Minimum-Threshold: The 32-bit absolute Minimum-Threshold value. The increase or decrease should be at least or above this value.

## 4.7. Report-Interval sub-TLV

The Report-Interval sub-TLV specifies the time interval in seconds when measured values are to be reported. The format of this sub-TLV is shown in Figure 8.

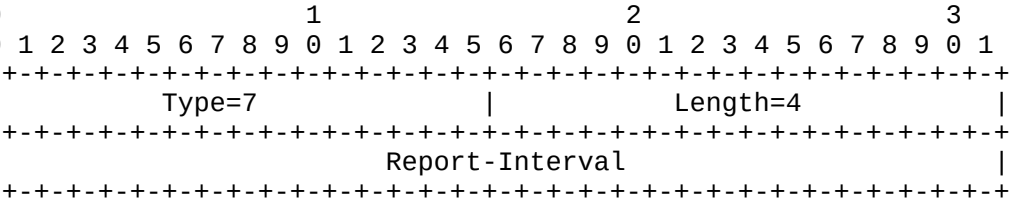


Figure 8: Report-Interval sub-TLV Format

The Type is 7, Length is 4 bytes, and the value comprises a 4-byte time interval, the valid range is from 0 to 604800, in seconds. The default value is 3600 seconds. The value 0 is used to disable the periodic reporting of the measurements.

## 4.8. Report-Upper-Lower-Bound sub-TLV

The Report-Upper-Lower-Bound sub-TLV specifies the upper bound value and lower bound value used to trigger an immediate reporting of the measurements when crossed. This may also result in the PCC taking an immediate local action on the LSP. The format of this sub-TLV is shown in Figure 9.

The anomaly flag is set to true in the reported measurement when the upper bound threshold is crossed in the up direction and set to false in the reported measurement when the lower bound threshold is crossed in the down direction.

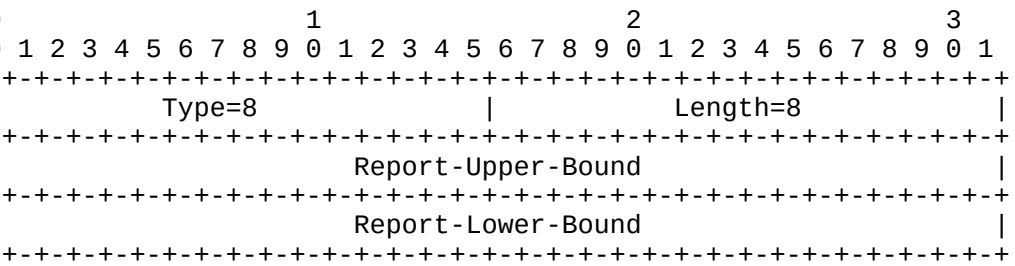


Figure 9: Report-Upper-Lower-Bound sub-TLV Format

The Type is 8, Length is 8 bytes, and the value comprises:

* Report-Upper-Bound: 32-bit absolute value.

  By default, upper bound is not set.

* Report-Lower-Bound: 32-bit absolute value.

By default, lower bound is not set. The lower bound value MUST be less than the upper bound value.

# 5. PCEP Extensions for Delay Measurement

## 5.1. Delay Measurement Capability Advertisement

During the PCEP Initialization phase, PCEP Speakers (PCE or PCC) advertise their support for DELAY-MEASUREMENT. A PCEP Speaker (PCE or PCC) includes the DELAY-MEASUREMENT-CAPABILITY TLV in the OPEN Object to advertise its support for PCEP Delay-Measurement extensions. The presence of the DELAY-MEASUREMENT-CAPABILITY TLV in the OPEN Object (in the Open message) indicates that the Delay Measurement capability is supported as described in this document. Additional procedures are defined as follows:

* The PCEP protocol extensions for Delay Measurement MUST NOT be used if one or both PCEP Speakers have not included the DELAY-MEASUREMENT-CAPABILITY TLV in their respective Open message.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the DELAY-MEASUREMENT-ATTRIBUTES TLV in the LSPA object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD21 (Delay-Measurement capability was not advertised) and terminate the PCEP session.

* Similarly, the PCEP speaker SHOULD generate error-value TBD23 (Two-Way Measurement capability was not advertised), TBD24 (One-Way Measurement capability was not advertised) and TBD25 (Loopback Measurement capability was not advertised) upon receipt of the DELAY-MEASUREMENT-ATTRIBUTES TLV in the LSPA object with Two-Way, One-Way, and Loopback request, respectively, when it did not advertise this capability.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the DELAY-MEASUREMENT object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD21 (Delay-Measurement capability was not advertised) and terminate the PCEP session.

### 5.1.1. DELAY-MEASUREMENT-CAPABILITY TLV

The DELAY-MEASUREMENT-CAPABILITY TLV is an optional TLV for use in the OPEN Object for Delay Measurement via PCEP capability advertisement. The format of this TLV is shown in Figure 10.

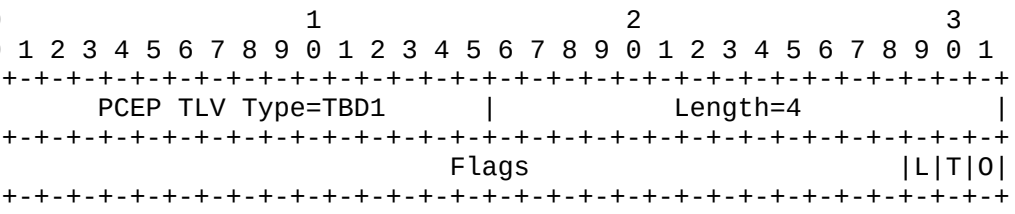


Figure 10: DELAY-MEASUREMENT-CAPABILITY TLV Format

The Type of the TLV is TBD1 and it has a fixed length of 4 bytes.

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

* O (One-way Delay Metric - 1 bit): if set to 1 by a PCC, the O Flag indicates that the PCC allows reporting of one-way delay metric information; if set to 1 by a PCE, the O Flag indicates that the PCE is capable of receiving one-way delay metric information from the PCC.

* T (Two-way Delay Metric - 1 bit): if set to 1 by a PCC, the T Flag indicates that the PCC allows reporting of two-way delay metric information; if set to 1 by a PCE, the T Flag indicates that the PCE is capable of receiving two-way delay metric information from the PCC.

* L (Loopback Delay Metric - 1 bit): if set to 1 by a PCC, the L Flag indicates that the PCC allows reporting of loopback delay metric information; if set to 1 by a PCE, the L Flag indicates that the PCE is capable of receiving loopback delay metric information from the PCC.

Unassigned bits are considered reserved. They MUST be set to 0 when sent and MUST be ignored when received.

Advertisement of the DELAY-MEASUREMENT-CAPABILITY TLV implies support for delay measurement, as well as the objects, TLVs and procedures defined in this document. Either the O, T or L flag MUST be set to 1 in the TLV.

## 5.2. DELAY-MEASUREMENT-ATTRIBUTES TLV

The DELAY-MEASUREMENT-ATTRIBUTES TLV provides the configurable parameters of the delay measurement feature.

The format of the DELAY-MEASUREMENT-ATTRIBUTES TLV is shown in Figure 11.

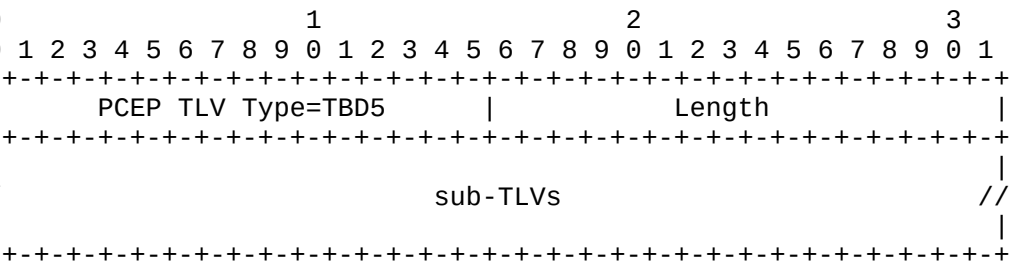


Figure 11: DELAY-MEASUREMENT-ATTRIBUTES TLV Format

PCEP TLV Type is defined as follows:

| Type | Name |
|---|---|
| TBD5 | DELAY-MEASUREMENT-ATTRIBUTES |

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

Value: Comprises of one or more sub-TLVs as described in Section 4 of this document.

The following sub-sections describe the parameters that are currently defined to be carried within this TLV. Any other parameters not defined for this TLV MUST be ignored.

### 5.2.1. Delay Measurement Enable

The Measurement-Enable sub-TLV specifies the delay metric mode enabled using the following flags:

| Bit | Description |
|---|---|
| 31 | One-Way Delay Metric Enabled |
| 30 | Two-Way Delay Metric Enabled |
| 29 | Loopback Delay Metric Enabled |

### 5.2.2. Delay Measurement Protocol

The Measurement-Protocol sub-TLV specifies that the given protocol type and mode are enabled for delay measurement.

### 5.2.3. Delay Measurement Transmit Interval

The Transmit-Interval sub-TLV specifies a time interval in milliseconds for the delay measurement test packet transmission.

#### 5.2.4. Delay Measurement Interval

The Measurement-Interval sub-TLV specifies a time interval in seconds for the delay metrics computation for the LSP.

#### 5.2.5. Delay Measurement Report Threshold

The Report-Threshold sub-TLV specifies the threshold value used to trigger an immediate reporting of the delay metrics bypassing the report-interval.

* Report-Threshold: Delay in microseconds, encoded as a 24-bit integer, as defined in [RFC7471].

The same report-threshold is used for all delay metric values.

#### 5.2.6. Delay Measurement Report Threshold Percentage

The Report-Threshold-Percentage sub-TLV specifies the threshold value used to trigger an immediate reporting of the metrics bypassing the report-interval.

The same report-threshold-percentage is used for all delay metric values.

#### 5.2.7. Delay Measurement Report Interval

The Report-Interval sub-TLV specifies the time interval in seconds when measured delay values are to be reported.

#### 5.2.8. Delay Measurement Upper Bound and Lower Bound

The Report-Upper-Lower-Bound sub-TLV specifies the upper bound (for going up direction) and lower bound (for going down direction) delay values in microseconds, and is used to trigger an immediate reporting of the delay values when crossed. This may also result in the PCC taking an immediate local action on the LSP.

### 5.3. DELAY-MEASUREMENT Object

The DELAY-MEASUREMENT Object with Object-Class (Value TBD9) is defined in this document to report the delay measurement of an LSP. The format of this Object is shown in Figure 12.

When the LSP is enabled with the delay measurement feature, the PCC SHOULD include the DELAY-MEASUREMENT Object to report the measured delay values to the PCE. The PCC SHOULD report average delay, min/max delay, and delay variations to the PCE, as well as the anomaly state in the Anomaly (A) flag based on the attributes signaled.

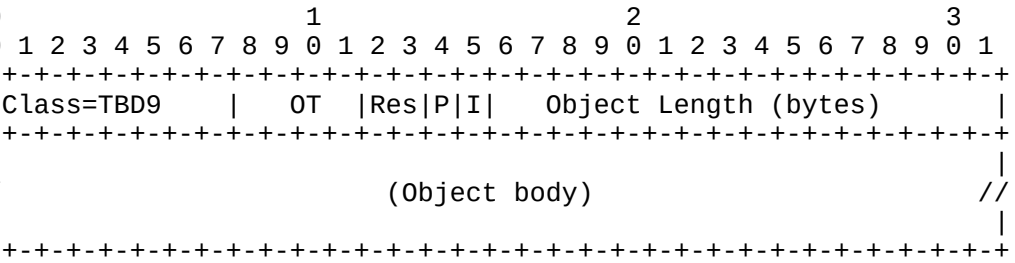


Figure 12: DELAY-MEASUREMENT Object Format

Object Length (16 bits): Specifies the total object length including the header, in bytes, as per [RFC5440].

Object-Types (OT) are defined as follows:

| Object-Type | Length | Name |
|---|---|---|
| 1 | 8 | Delay Measurement Status |
| 2 | 8 | One-Way Delay Metric Value |
| 3 | 12 | One-Way Delay Metric Min/Max Values |
| 4 | 8 | One-Way Delay Variation Metric Value |
| 5 | 8 | Two-Way Delay Metric Value |
| 6 | 12 | Two-Way Delay Metric Min/Max Values |
| 7 | 8 | Two-Way Delay Variation Metric Value |
| 8 | 8 | Loopback Delay Metric Value |
| 9 | 12 | Loopback Delay Metric Min/Max Values |
| 10 | 8 | Loopback Delay Variation Metric Value |

All delay values are reported in microseconds, encoded as a 24-bit integer, as defined in [RFC7471]. When set to the maximum value 16,777,215 (16.777215 sec), the delay is at least that value and may be larger.

The object body formats are defined as shown in Figure 13, Figure 14, Figure 15, and Figure 16.

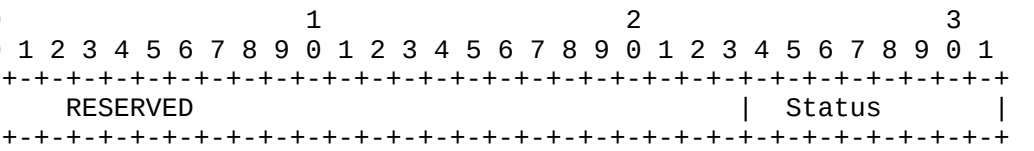


Figure 13: DELAY-MEASUREMENT Object For Delay Measurement Status

* Delay Measurement Status: Indicates the Status of Delay Measurement as: (1) Active, (2) Failed, (3) Errored.

* RESERVED: This field is reserved for future use. It MUST be set to 0 when sent and MUST be ignored when received.

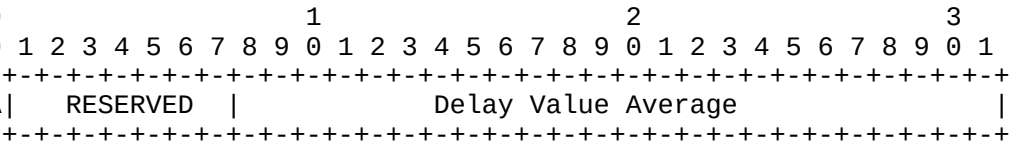


Figure 14: DELAY-MEASUREMENT Object For One-Way, Two-Way and Loopback Average

* One-way Delay Value Average: Average Delay of the LSP in one (forward) direction.

* Two-way Delay Value Average: Average Delay of the LSP in both forward and reverse directions.

* Loopback Delay Value Average: Average Delay of the LSP in both forward and reverse directions.

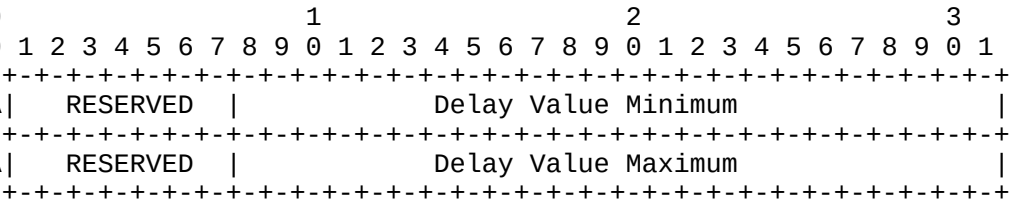


Figure 15: DELAY-MEASUREMENT Object For One-Way, Two-Way and Loopback Min/Max

* One-Way Delay Value Minimum/Maximum: Minimum and Maximum values of the Delay of the LSP in one (forward) direction.

* Two-Way Delay Value Minimum/Maximum: Minimum and Maximum values of the Delay of the LSP in both forward and reverse directions.

* Loopback Delay Value Minimum/Maximum: Minimum and Maximum values of the Delay of the LSP in both forward and reverse directions.

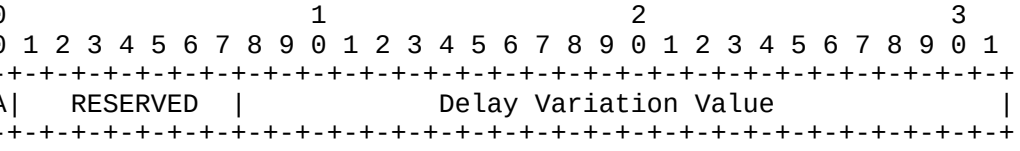


Figure 16: DELAY-MEASUREMENT Object For One-Way, Two-Way and Loopback Variation

* One-way Delay Variation Value: Average Delay Variation of the LSP in the forward direction.

* Two-way Delay Variation Value: Average Delay Variation of the LSP in both forward and reverse directions.

* Loopback Delay Variation Value: Average Delay Variation of the LSP in both forward and reverse directions.

# 6. PCEP Extensions for Loss Measurement

## 6.1. Loss Measurement Capability Advertisement

During the PCEP Initialization Phase, PCEP Speakers (PCE or PCC) advertise their support for LOSS-MEASUREMENT. A PCEP Speaker includes the LOSS-MEASUREMENT-CAPABILITY TLV in the OPEN Object to advertise its support for PCEP Loss-Measurement extensions. The presence of the LOSS-MEASUREMENT-CAPABILITY TLV in the OPEN Object (in the Open message) indicates that the Loss Measurement capability is supported as described in this document. Additional procedures are defined as follows:

* The PCEP protocol extensions for Loss Measurement MUST NOT be used if one or both PCEP Speakers have not included the LOSS-MEASUREMENT-CAPABILITY TLV in their respective Open message.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the LOSS-MEASUREMENT-ATTRIBUTES TLV in the LSPA object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD22 (Loss-Measurement capability was not advertised) and terminate the PCEP session.

* Similarly, the PCEP speaker SHOULD generate error-value TBD23 (Two-Way Measurement capability was not advertised), TBD24 (One-Way Measurement capability was not advertised) and TBD25 (Loopback

Measurement capability was not advertised) upon receipt of the LOSS-MEASUREMENT-ATTRIBUTES TLV in the LSPA object with two-way, one-way and loopback measurement request, respectively, when it did not advertise this capability.

* Further, the PCEP speaker SHOULD generate error-value TBD26 (Inferred Mode Loss Measurement capability was not advertised) and TBD27 (Direct Mode Loss Measurement capability was not advertised) upon receipt of the LOSS-MEASUREMENT-ATTRIBUTES TLV in the LSPA object with Inferred Mode loss measurement request and Direct Mode loss measurement request, respectively, when it did not advertise this capability.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the LOSS-MEASUREMENT object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD22 (Loss-Measurement capability was not advertised) and terminate the PCEP session.

#### 6.1.1. LOSS-MEASUREMENT-CAPABILITY TLV

The LOSS-MEASUREMENT-CAPABILITY TLV is an optional TLV for use in the OPEN Object for Loss Measurement via PCEP capability advertisement. Its format is shown in Figure 17.

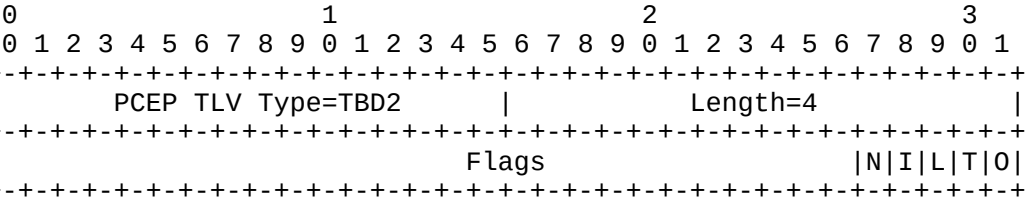


Figure 17: LOSS-MEASUREMENT-CAPABILITY TLV Format

The Type of the TLV is TBD2 and it has a fixed length of 4 bytes.

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

* O (One-Way Metric - 1 bit): if set to 1 by a PCC, the O Flag indicates that the PCC allows reporting of one-way loss metric information; if set to 1 by a PCE, the O Flag indicates that the PCE is capable of receiving one-way loss metric information from the PCC.

* T (Two-Way Metric - 1 bit): if set to 1 by a PCC, the T Flag indicates that the PCC allows reporting of two-way loss metric information; if set to 1 by a PCE, the T Flag indicates that the PCE is capable of receiving two-way loss metric information from the PCC.

* L (Loopback Metric - 1 bit): if set to 1 by a PCC, the L Flag indicates that the PCC allows reporting of loopback loss metric information; if set to 1 by a PCE, the L Flag indicates that the PCE is capable of receiving loopback loss metric information from the PCC.

* I (Inferred Loss Measurement Mode - 1 bit): if set to 1 by a PCC, the I Flag indicates that the PCC allows reporting of inferred mode loss measurement information; if set to 1 by a PCE, the I Flag indicates that the PCE is capable of receiving inferred mode loss measurement information from the PCC.

* N (Direct Loss Measurement Mode - 1 bit): if set to 1 by a PCC, the N Flag indicates that the PCC allows reporting of direct mode loss measurement information; if set to 1 by a PCE, the N Flag indicates that the PCE is capable of receiving direct mode loss measurement information from the PCC.

Unassigned bits are considered reserved. They MUST be set to 0 when sent and MUST be ignored when received.

Advertisement of the LOSS-MEASUREMENT-CAPABILITY TLV implies support for loss measurement, as well as the objects, TLVs and procedures defined in this document. Either the O, T or L flag MUST be set to 1 in the TLV. Similarly, either the I or N flag MUST be set to 1 in the TLV.

### 6.2. LOSS-MEASUREMENT-ATTRIBUTES TLV

The LOSS-MEASUREMENT-ATTRIBUTES TLV provides the configurable parameters of the loss measurement feature.

The format of the LOSS-MEASUREMENT-ATTRIBUTES TLV is shown in Figure 18.

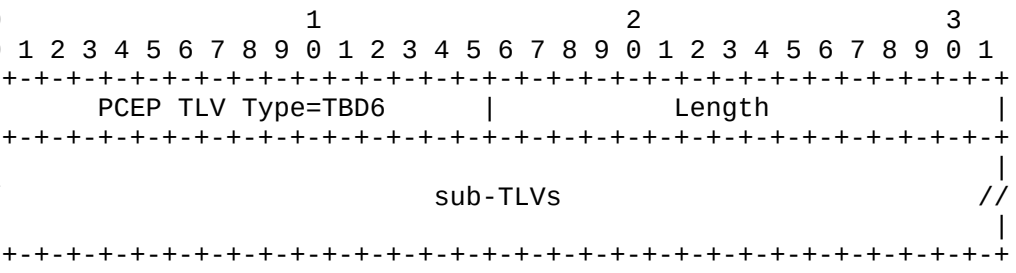


Figure 18: LOSS-MEASUREMENT-ATTRIBUTES TLV Format

PCEP TLV Type is defined as follows:

| Type | Name |
|---|---|
| TBD6 | LOSS-MEASUREMENT-ATTRIBUTES |

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

Value: Comprises of one or more sub-TLVs as described in Section 4 of this document.

The following sub-sections describe the parameters that are currently defined to be carried within this TLV. Any other parameters not defined for this TLV MUST be ignored.

### 6.2.1. Loss Measurement Enable

The Measurement-Enable sub-TLV specifies the loss metric mode enabled using the following flags:

| Bit | Description |
|---|---|
| 28 | One-Way Loss Metric Enabled |
| 27 | Two-Way Loss Metric Enabled |
| 26 | Loopback Loss Metric Enabled |
| 25 | Inferred Loss Metric Enabled |
| 24 | Direct Loss Metric Enabled |

### 6.2.2. Loss Measurement Protocol

The Measurement-Protocol sub-TLV specifies that the given protocol type and mode are enabled for loss measurement.

#### 6.2.3. Loss Measurement Transmit Interval

The Transmit-Interval sub-TLV specifies a time interval in milliseconds for the loss measurement test packet transmission.

#### 6.2.4. Loss Measurement Interval

The Measurement-Interval sub-TLV specifies a time interval in seconds for the loss metric computation for the LSP.

#### 6.2.5. Loss Measurement Report Threshold

The Report-Threshold sub-TLV specifies the threshold value used to trigger an immediate reporting of the loss metrics bypassing the report-interval.

* Report-Threshold: This 24-bit field identifies the packet loss as a percentage of the total packets sent or received. The encoding is as per [RFC7471].

The same report-threshold is used for all loss metric values.

#### 6.2.6. Loss Measurement Report Threshold Percentage

The Report-Threshold-Percentage sub-TLV specifies the threshold value used to trigger an immediate reporting of the loss metrics bypassing the report-interval.

The same report-threshold-percentage is used for all loss metric values.

#### 6.2.7. Loss Measurement Report Interval

The Report-Interval sub-TLV specifies the time interval in seconds when measured loss values are to be reported.

#### 6.2.8. Loss Measurement Upper Bound and Lower Bound

The Report-Upper-Lower-Bound sub-TLV specifies the upper bound (for going up direction) and lower bound (for going down direction) values in percentage packet loss, and is used to trigger an immediate reporting of the packet loss values when crossed. This may also result in the PCC taking an immediate local action on the LSP.

### 6.3. LOSS-MEASUREMENT Object

The LOSS-MEASUREMENT Object with Object-Class (Value TBD10) is defined in this document to report the packet loss measurement of an LSP. The format of this Object is shown in Figure 19.

When the LSP is enabled with the loss measurement feature, the PCC SHOULD include the LOSS-MEASUREMENT Object to report the measured packet loss to the PCE, as well as the anomaly state in the Anomaly (A) flag.

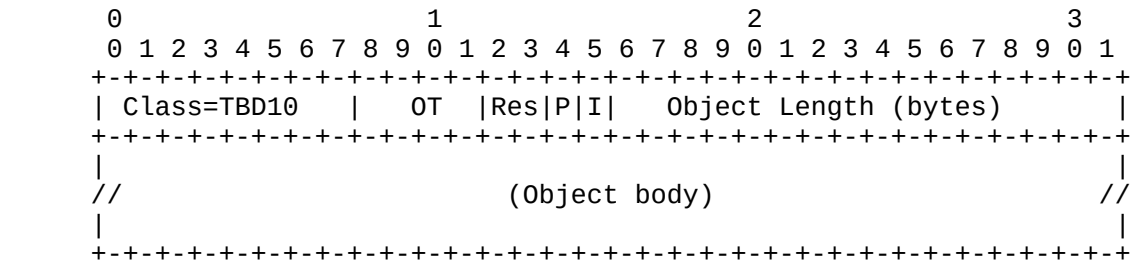


Figure 19: LOSS-MEASUREMENT Object Format

Object Length (16 bits): Specifies the total object length including the header in bytes, as per [RFC5440].

Object-Types (OT) are defined as follows:

| Object-Type | Length | Name |
|---|---|---|
| 1 | 8 | Loss Measurement Status |
| 2 | 8 | Tx Packets-Lost |
| 3 | 8 | Rx Packets-Lost |
| 4 | 12 | Total Packets-Sent-Received |

The object body format for Loss Measurement Status is shown in Figure 20.

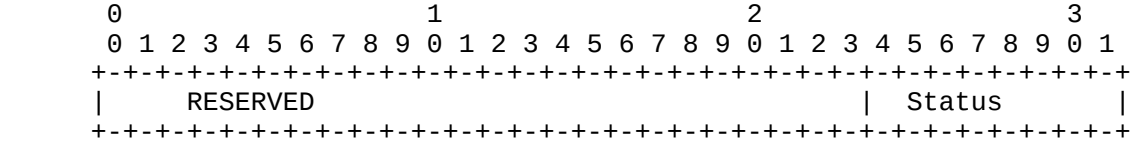


Figure 20: LOSS-MEASUREMENT Object For Loss Measurement Status

* Loss Measurement Status: Indicates the Status of Loss Measurement as: (1) Active, (2) Failed, (3) Errored.

* RESERVED: This field is reserved for future use. It MUST be set to 0 when sent and MUST be ignored when received.

The object body format for Packets-Lost is shown in Figure 21.

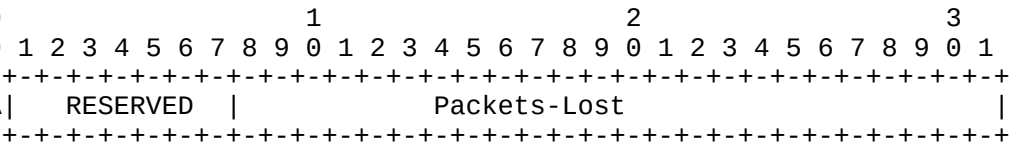


Figure 21: LOSS-MEASUREMENT Object For Packets Lost

* Packets-Lost: This 24-bit field identifies the packet loss as a percentage of the total packets transmitted, encoded as per [RFC7471].

* RESERVED: This field is reserved for future use. It MUST be set to 0 when sent and MUST be ignored when received.

The object body format for Total Packets Sent and Received is shown in Figure 22.

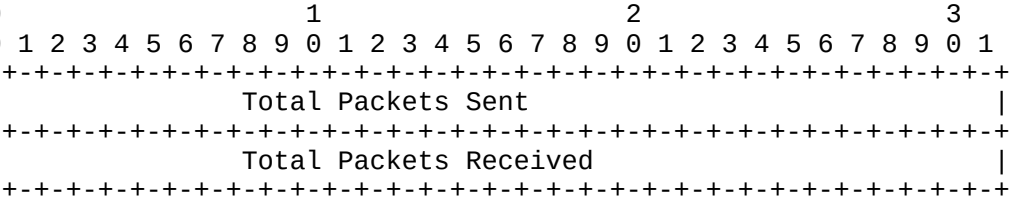


Figure 22: LOSS-MEASUREMENT Object For Total Packets Sent and Received

* Total Packets Sent: This 32-bit field identifies the total packets sent.

* Total Packets Received: This 32-bit field identifies the total packets received.

## 7. PCEP Extensions for Bandwidth Utilization

### 7.1. Bandwidth Utilization Capability Advertisement

During the PCEP Initialization Phase, PCEP Speakers (PCE or PCC) advertise their support for bandwidth utilization reporting. A PCEP Speaker includes the "BANDWIDTH-UTILIZATION-CAPABILITY" TLV in the OPEN Object to advertise its support for PCEP extensions. The presence of the "BANDWIDTH-UTILIZATION-CAPABILITY" TLV in the OPEN Object (in the Open message) indicates that the bandwidth utilization reporting is supported as described in this document. Additional procedures are defined as follows:

* The PCEP protocol extensions for bandwidth utilization MUST NOT be used if one or both PCEP Speakers have not included the "BANDWIDTH-UTILIZATION-CAPABILITY" TLV in their respective Open message.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the BANDWIDTH-UTILIZATION-ATTRIBUTES TLV in the LSPA object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error- value TBD28 (Bandwidth utilization capability was not advertised) and terminate the PCEP session.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the BANDWIDTH-UTILIZATION object of type TBD12, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD28 (Bandwidth utilization capability was not advertised) and terminate the PCEP session.

#### 7.1.1. BANDWIDTH-UTILIZATION-CAPABILITY TLV

The BANDWIDTH-UTILIZATION-CAPABILITY TLV is an optional TLV for use in the OPEN Object for Bandwidth Utilization reporting via PCEP capability advertisement. Its format is shown in Figure 23.

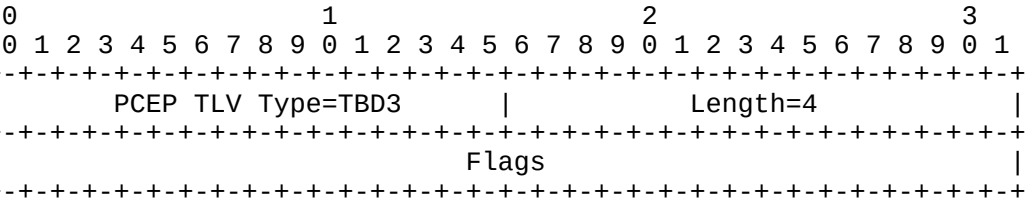


Figure 23: BANDWIDTH-UTILIZATION-CAPABILITY TLV Format

The Type of the TLV is TBD3 and it has a fixed length of 4 bytes.

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 when sent and MUST be ignored when received.

Advertisement of the BANDWIDTH-UTILIZATION-CAPABILITY TLV implies support for bandwidth utilization reporting, as well as the objects, TLVs and procedures defined in this document.

## 7.2. BW-UTILIZATION-MEASUREMENT-ATTRIBUTES TLV

The BW-UTILIZATION-MEASUREMENT-ATTRIBUTES TLV provides the configurable parameters of the bandwidth utilization feature.

The format of the BW-UTILIZATION-MEASUREMENT-ATTRIBUTES TLV is shown in Figure 24.

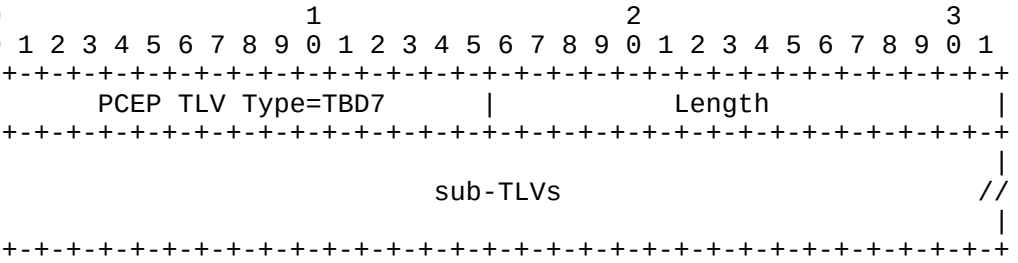


Figure 24: BW-UTILIZATION-MEASUREMENT-ATTRIBUTES TLV Format

PCEP TLV Type is defined as follows:

| Type | Name |
|---|---|
| TBD7 | BW-UTILIZATION-MEASUREMENT-ATTRIBUTES |

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

Value: Comprises of one or more sub-TLVs as described in Section 4 of this document.

For reporting bandwidth utilization, the last reported MaxSampleBw (see [RFC8733]) value is compared with the MaxSampleBW from the current interval to detect the threshold crossing.

The following sub-sections describe the parameters that are currently defined to be carried within this TLV. Any other parameters not defined for this TLV MUST be ignored.

#### 7.2.1. Bandwidth Utilization Measurement Enable

The Measurement-Enable sub-TLV specifies that the bandwidth utilization reporting is enabled using the following flag:

| Bit | Description |
|---|---|
| 23 | Bandwidth Utilization Reporting Enabled |

#### 7.2.2. Bandwidth Utilization Measurement Interval

The Measurement-Interval sub-TLV specifies a time interval in seconds for the bandwidth samples collection for the LSP.

#### 7.2.3. Bandwidth Utilization Report Threshold

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

* Threshold: The absolute threshold bandwidth value in 32-bits, encoded in IEEE floating-point format as described in [IEEE.754.1985], expressed in bytes per second.

#### 7.2.4. Bandwidth Utilization Report Threshold Percentage

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

#### 7.2.5. Bandwidth Utilization Report Interval

The Report-Interval sub-TLV specifies a time interval in seconds when the collected bandwidth samples are to be reported to the PCE. The number of bandwidth samples in the report interval is computed using the measurement interval.

#### 7.2.6. Bandwidth Utilization Upper Bound and Lower Bound

The Report-Upper-Lower-Bound sub-TLV specifies the upper bound and lower bound bandwidth values encoded in IEEE floating-point format as described in [IEEE.754.1985], expressed in bytes per second, and is used to trigger an immediate reporting when crossed. This may also result in the PCC taking an immediate local action on the LSP.

### 7.3. BANDWIDTH Object For Reporting

A new object-type for the existing BANDWIDTH Object (Object-Class 5) is defined to report the bandwidth utilization of an LSP.

When the LSP is enabled with the bandwidth utilization reporting, the PCC SHOULD include the BANDWIDTH-UTILIZATION Object to report the bandwidth utilization of the LSP to the PCE in the PCRpt message.

The object-type is TBD12, the object length is variable with multiples of 4 bytes.

The object body format is shown in Figure 25.

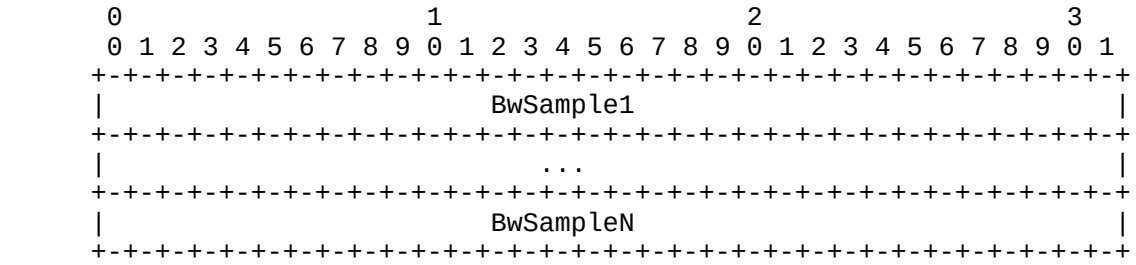


Figure 25: BANDWIDTH-UTILIZATION Object Body Format For Reporting Bandwidth

* BwSample: The utilized bandwidth, (the average BwSample collected at the end of each measurement-interval) encoded in IEEE floating-point format as described in [IEEE.754.1985], expressed in bytes per second.

## 8. PCEP Extensions for Liveness Detection Using PM

### 8.1. Liveness Detection Using PM

During the PCEP Initialization Phase, PCEP Speakers (PCE or PCC) advertise their support for LIVENESS-DETECTION. A PCEP Speaker includes the LIVENESS-DETECTION-CAPABILITY TLV in the OPEN Object to advertise its support for PCEP Liveness-Detection extensions. The presence of the LIVENESS-DETECTION-CAPABILITY TLV in the OPEN Object (in the Open message) indicates that the liveness detection capability is supported as described in this document. Additional procedures are defined as follows:

* The PCEP protocol extensions for Liveness Detection MUST NOT be used if one or both PCEP Speakers have not included the LIVENESS-DETECTION-CAPABILITY TLV in their respective Open message.

* If a PCEP speaker supports the extensions of this document but did not advertise this capability, then upon receipt of the LIVENESS-DETECTION-ATTRIBUTES TLV in the LSPA object, it SHOULD generate a PCErr with error-type 19 (Invalid Operation), error-value TBD29 (Liveness-Detection capability was not advertised) and terminate the PCEP session.

#### 8.1.1. LIVENESS-DETECTION-CAPABILITY TLV

The LIVENESS-DETECTION-CAPABILITY TLV is an optional TLV for use in the OPEN Object for Liveness Detection via PCEP capability advertisement. Its format is shown in Figure 26.

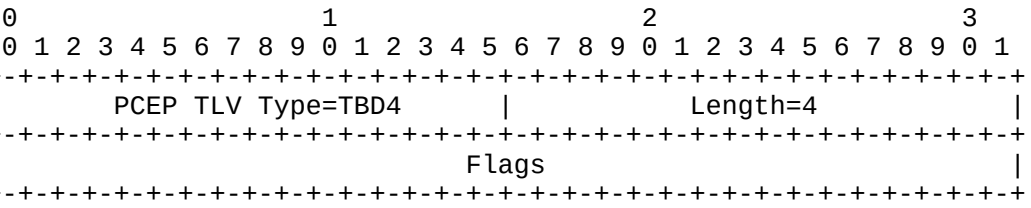


Figure 26: LIVENESS-DETECTION-CAPABILITY TLV Format

The Type of the TLV is TBD4 and it has a fixed length of 4 bytes.

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

Unassigned bits are considered reserved. They MUST be set to 0 when sent and MUST be ignored when received.

Advertisement of the LIVENESS-DETECTION-CAPABILITY TLV implies support for liveness detection, as well as the objects, TLVs and procedures defined in this document.

### 8.2. LIVENESS-DETECTION-ATTRIBUTES TLV

The LIVENESS-DETECTION-ATTRIBUTES TLV provides the configurable parameters of the liveness detection feature.

The format of the LIVENESS-DETECTION-ATTRIBUTES TLV is shown in Figure 27.

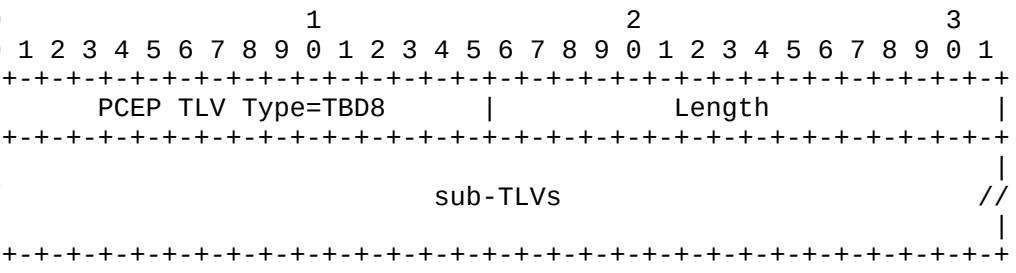


Figure 27: LIVENESS-DETECTION-ATTRIBUTES TLV Format

PCEP TLV Type is defined as follows:

| Type | Name |
|---|---|
| TBD8 | LIVENESS-DETECTION-ATTRIBUTES |

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

Value: Comprises of one or more sub-TLVs as described in Section 4 of this document.

The following sub-sections describe the parameters that are currently defined to be carried within this TLV. Any other parameters not defined for this TLV MUST be ignored.

### 8.2.1. Liveness Detection Enable

The Measurement-Enable sub-TLV specifies the liveness detection enabled using the following flags:

| Bit | Description |
|---|---|
| 22 | Liveness Detection Enabled |

### 8.2.2. Liveness Detection Protocol

The Measurement-Protocol sub-TLV specifies that the given protocol type and loopback mode are enabled for liveness detection.

### 8.2.3. Liveness Detection Transmit Interval

The Transmit-Interval sub-TLV specifies a time interval in milliseconds for the liveness detection loss test packet transmission.

### 8.2.4. Liveness Detection Interval

The Measurement-Interval sub-TLV specifies a time interval in seconds for the liveness failure detection. The measurement interval MUST be a multiple of transmit interval.

## 8.3. LIVENESS-DETECTION Object

The LIVENESS-DETECTION Object with Object-Class (Value TBD11) is defined in this document to report the liveness state of an LSP. The format of this Object is shown in Figure 28.

When the LSP is enabled with the liveness detection feature, the PCC SHOULD include the LIVENESS-DETECTION Object to report the liveness state.

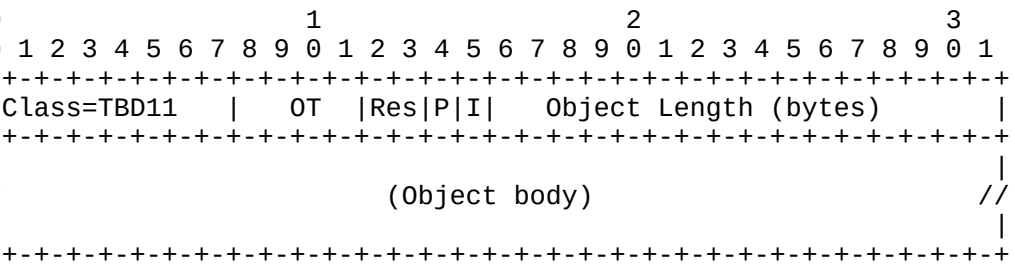


Figure 28: LIVENESS-DETECTION Object Format

Object Length (16 bits): Specifies the total object length including the header, in bytes [RFC5440].

Object-Types (OT) are defined as follows:

| Object-Type | Length | Name |
|---|---|---|
| 1 | 8 | Liveness State |

The object body format for Liveness Detection State is shown in Figure 29.

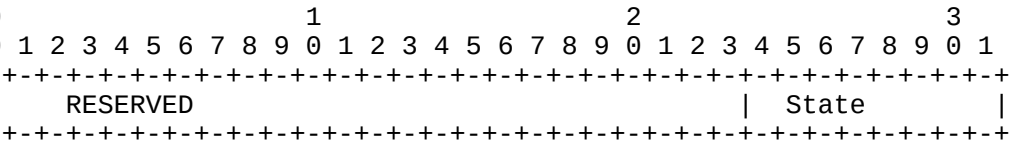


Figure 29: LIVENESS-DETECTION Object Format For Liveness State

* Liveness Detection State: Indicates the State of Liveness Detection as: (1) Up, (2) Down, (3) Errored.

* RESERVED: This field is reserved for future use. It MUST be set to 0 when sent and MUST be ignored when received.

## 9. PCEP Procedures

The following procedures are defined for the extensions to different PCEP messages for reporting performance measurement and liveness detection.

### 9.1. MEASUREMENT-ATTRIBUTES TLVs in LSPA Object

* For a PCE-Initiated LSP [RFC8281] with reporting features enabled, the corresponding MEASUREMENT-ATTRIBUTES TLV for each measurement MUST be included in the LSPA Object with the PCInitiate message.

* For a PCE-Initiated LSP [RFC8281] with reporting features enabled, the corresponding MEASUREMENT-ATTRIBUTES TLV for each measurement is carried in the PCUpd message in the LSPA Object in order to make updates to the attributes such as the Report-Interval.

* For a PCC-Initiated LSP with reporting features enabled, when the LSP is delegated to the PCE, the corresponding MEASUREMENT-ATTRIBUTES TLV for each measurement MUST be included in the LSPA Object of the PCRpt message.

* The various MEASUREMENT-ATTRIBUTES TLVs are encoded in all PCEP messages for the LSP with reporting features enabled, the absence of the corresponding MEASUREMENT-ATTRIBUTES TLV indicates that the PCEP speaker wishes to disable the feature.

### 9.2. LSP Measurement Notification Using MEASUREMENT Objects

When an LSP is enabled with a measurement reporting feature, the PCC SHOULD include the corresponding MEASUREMENT Object to notify the measured values to the PCE.

[RFC5440] defines request-notification. This message is extended for LSP Measurement Notification (type TBD13). It carries one or more LSPs, and each LSP may contain one or more paths information if multipath [I-D.ietf-pce-multipath] capability has been exchanged between the PCEP speakers. Each path carries individual performance measurement data.

The reception of this message is for informational purposes, and does not replace the PcUpd message and MUST NOT manipulate the ERO/RRO forwarding hop instructions and MUST NOT be considered as an alternative for PcUpd.

The RBNF format of the LSP Measurement Notification message (PCNtf) (type TBD13) is defined as follows:

```
<PCNtf Message> ::= <Common Header>
                    <notify-list>

<notify-list> ::= <notify> [<notify-list>]

<notify> ::= [<request-id-list>]
             [<lsp-list>]
             <notification-list>

<request-id-list> ::= <RP> [<request-id-list>]

<lsp-list> ::= <LSP> [<path>] [<lsp-list>]

<notification-list> ::= <NOTIFICATION> [<notification-list>]

<path> ::= <intended-path> [<actual-path>]

<intended-path> ::= ( [<ERO>] <attribute-list>   )  |
                    ( <PATH-ATTRIB> [<ERO>] <attribute-list>
                      [<intended-path-multipath>] )

<intended-path-multipath> ::= ( <PATH-ATTRIB> [<ERO>]
                                [<intended-path-multipath>] )

<actual-path> ::= ( [<RRO>] <attribute-list>     )  |
                  ( <PATH-ATTRIB> [<RRO>] <attribute-list>
                    [<actual-path-multipath>]    )

<actual-path-multipath> ::= ( <PATH-ATTRIB> [<RRO>]
                              [<actual-path-multipath>] )

<attribute-list> ::= [<BANDWIDTH>]
                     [<DELAY-MEASUREMENT>]
                     [<LOSS-MEASUREMENT>]
                     [<LIVENESS-DETECTION>]
                     [<metric-list>]

<metric-list> ::= <METRIC> [<metric-list>]
```

In the case of single ERO/RRO, an implementation MAY omit carrying the ERO/RRO in the LSP Measurement Notification when the previous message carried it. An implementation MAY omit carrying the ERO/RRO in the LSP Measurement Notification when the PATH ID [I-D.ietf-pce-multipath] is carried.

## 10. Scaling Considerations

It should be noted that when the measurement reporting is deployed under LSP scaling, it can lead to frequent notification updates to the PCE. Operators are advised to set the values of various measurement reporting parameters appropriate for the deployed LSP scale.

As the LSP Measurement Notification may carry measurement information for a list of LSPs, an implementation MAY limit the number of LSPs in the list to keep the message size small.

If a PCE gets overwhelmed, it can notify the PCC to temporarily suspend the reporting of the measurements as described below.

### 10.1. Notification for Overwhelmed State

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 SHOULD notify its PCEP peer that it is overwhelmed, and on receipt of such notification, the peer SHOULD NOT send any PCEP messages related to measurement reporting. If a PCEP message related to measurement reporting is received, it MUST be silently ignored.

* When a PCEP speaker is overwhelmed, it SHOULD notify its peer by sending a PCNtf message with Notification Type = TBD14 (PM Overwhelm State) and Notification Value = 1 (Entering PM overwhelm state).

* Optionally, the OVERLOADED-DURATION TLV [RFC5440] MAY be included that specifies the time period during which no further PCEP messages related to PM should be sent.

* When the PCEP speaker is no longer in the overwhelmed state and is available to process the PM reporting, it SHOULD notify its peer by sending a PCNtf message with Notification Type = TBD14 (PM Overwhelm State) and Notification Value = 2 (Clearing PM overwhelm state).

## 11. Security Considerations

This document defines new MEASUREMENT-ATTRIBUTES TLVs, CAPABILITY TLVs and MEASUREMENT Objects for reporting loss and delay measurements, liveness detection, and bandwidth utilization that do not add additional security concerns beyond those discussed in [RFC5440], [RFC8231], [RFC8281] and [RFC8664].

Some deployments may find the reporting of the performance measurement, liveness detection, and bandwidth utilization information as extra sensitive as it could be used to influence the LSP path computation and LSP setup with an 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 deployments should employ suitable PCEP security mechanisms like the TCP Authentication Option (TCP-AO) [RFC5925] or Transport Layer Security [RFC8253].

## 12. Operational Considerations

The manageability requirements and considerations listed in [RFC5440], [RFC8231], [RFC8281], and [I-D.ietf-pce-multipath] apply to the PCEP protocol extensions defined in this document. Additional operational requirements and considerations are listed in this section.

### 12.1. Control of Function and Policy

The performance measurement reporting SHOULD be controlled per LSP basis (at the PCC or PCE) and the values for feature attributes e.g. measurement-interval, report-interval, report-threshold SHOULD be configurable by an operator.

### 12.2. Information and Data Models

A Management Information Base (MIB) module for modeling PCEP is described in [RFC7420]. However, one may prefer a mechanism for configuration using the PCEP YANG data model [RFC9826]. These SHOULD be enhanced to provide controls and indicators for supporting the performance measurement reporting feature. Support for various configuration knobs as well as for counters of messages sent/received containing the TLVs (defined in this document) SHOULD be added.

### 12.3. Verify Correct Operations

Mechanisms defined in this document do not imply any new operational verification requirements.

### 12.4. Requirements on Other Protocols

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

### 12.5. 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 the performance measurement reporting feature. An implementation MAY allow a limit to be placed on the rate of measurement reporting 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 reaches a threshold.

## 13. IANA Considerations

### 13.1. Measurement Capability TLV Types

This document defines the following new PCEP TLVs; IANA is requested to make the following allocations from the "PCEP TLV Type Indicators" registry. http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators

| Type | Name | Reference |
|---|---|---|
| TBD1 | DELAY-MEASUREMENT-CAPABILITY | [This document] |
| TBD2 | LOSS-MEASUREMENT-CAPABILITY | [This document] |
| TBD3 | BANDWIDTH-UTILIZATION-CAPABILITY | [This document] |
| TBD4 | LIVENESS-DETECTION-CAPABILITY | [This document] |

### 13.2. Flag Fields for MEASUREMENT-CAPABILITY TLVs

IANA is requested to create two new registries as defined in this section to manage the Flag field of the DELAY-MEASUREMENT-CAPABILITY TLV and LOSS-MEASUREMENT-CAPABILITY TLV.

New bit numbers are allocated only by an IETF Review action [RFC8126]. Each bit should be tracked using the following qualities:

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

#### 13.2.1. Flag Fields for DELAY-MEASUREMENT-CAPABILITY TLV

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

The following values are defined in this document for the Flag field for DELAY-MEASUREMENT-CAPABILITY TLV:

| Bit | Description | Reference |
|---|---|---|
| 31 | One-way Delay Measurement | [This document] |
| 30 | Two-way Delay Measurement | [This document] |
| 29 | Loopback Delay Measurement | [This document] |

#### 13.2.2. Flag Fields for LOSS-MEASUREMENT-CAPABILITY TLV

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

The following values are defined in this document for the Flag field for LOSS-MEASUREMENT-CAPABILITY TLV:

| Bit | Description | Reference |
|---|---|---|
| 31 | One-Way Loss Measurement | [This document] |
| 30 | Two-Way Loss Measurement | [This document] |
| 29 | Loopback Loss Measurement | [This document] |
| 28 | Inferred Loss Measurement Mode | [This document] |
| 27 | Direct Loss Measurement Mode | [This document] |

### 13.3. MEASUREMENT-ATTRIBUTES TLVs

This document defines the following new PCEP TLV Types; IANA is requested to make the following TLV type allocations from the "PCEP TLV Type Indicators" registry. http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-tlv-type-indicators

| Type | Name | Reference |
|---|---|---|
| TBD5 | DELAY-MEASUREMENT-ATTRIBUTES | [This document] |
| TBD6 | LOSS-MEASUREMENT-ATTRIBUTES | [This document] |
| TBD7 | BW-UTILIZATION-MEASUREMENT-ATTRIBUTES | [This document] |
| TBD8 | LIVENESS-DETECTION-ATTRIBUTES | [This document] |

### 13.3.1. The Sub-TLVs for MEASUREMENT-ATTRIBUTES TLVs

IANA is requested to create a "MEASUREMENT-ATTRIBUTES Sub-TLV Types" sub-registry in the "PCEP TLV Type Indicators" registry. New sub-TLVs are allocated only by an IETF Review action [RFC8126].

This document defines the following sub-TLV types:

| Type | Name | Reference |
|---|---|---|
| 0 | Reserved | [This document] |
| 1 | Measurement-Enable sub-TLV | [This document] |
| 2 | Transmit-Interval sub-TLV | [This document] |
| 3 | Measurement-Protocol sub-TLV | [This document] |
| 4 | Measurement-Interval sub-TLV | [This document] |
| 5 | Report-Threshold sub-TLV | [This document] |
| 6 | Report-Threshold-Percentage sub-TLV | [This document] |
| 7 | Report-Interval sub-TLV | [This document] |
| 8 | Report-Upper-Lower-Bound sub-TLV | [This document] |
| 9-65535 | Unassigned | [This document] |

### 13.3.2. Flag Fields in Measurement-Enable sub-TLV

IANA is requested to create a registry to manage the Flag field of the Measurement-Enable sub-TLV.

New bit numbers are allocated only by an IETF Review action [RFC8126]. Each bit should be tracked with the following qualities:

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

The following values are defined in this document for the Flag field.

| Bit | Description | Reference |
|---|---|---|
| 31 | One-Way Delay Measurement Enabled | [This document] |
| 30 | Two-Way Delay Measurement Enabled | [This document] |
| 29 | Loopback Delay Measurement Enabled | [This document] |
| 28 | One-Way Loss Measurement Enabled | [This document] |
| 27 | Two-Way Loss Measurement Enabled | [This document] |
| 26 | Loopback Loss Measurement Enabled | [This document] |
| 25 | Inferred Loss Measurement Enabled | [This document] |
| 24 | Direct Loss Measurement Enabled | [This document] |
| 23 | Bandwidth Utilization Reporting Enabled | [This document] |
| 22 | Liveness Detection Enabled | [This document] |

### 13.4. Measurement Object-Class

This document defines Object-Class for the following Objects; IANA is requested to make the following allocations from the "PCEP Objects" registry. http://www.iana.org/assignments/pcep/pcep.xhtml#pcep-objects

| Object-Class | Name | Reference |
|---|---|---|
| TBD9 | DELAY-MEASUREMENT Object | [This document] |
| TBD10 | LOSS-MEASUREMENT Object | [This document] |
| TBD11 | LIVENESS-DETECTION Object | [This document] |

#### 13.4.1. DELAY-MEASUREMENT Object-Types

IANA is requested to create a "DELAY-MEASUREMENT Object-Types" sub-registry for the DELAY-MEASUREMENT Object (Object-class TBD9).

This document defines the following object-types:

| Object-Type | Name | Reference |
|---|---|---|
| 0 | Reserved | [This document] |
| 1 | Delay Measurement Status | [This document] |
| 2 | One-Way Delay Measurement Value | [This document] |
| 3 | One-Way Delay Measurement Min/Max Values | [This document] |
| 4 | One-Way Delay Variation Measurement Value | [This document] |
| 5 | Two-Way Delay Measurement Value | [This document] |
| 6 | Two-Way Delay Measurement Min/Max Values | [This document] |
| 7 | Two-Way Delay Variation Measurement Value | [This document] |
| 8 | Loopback Delay Measurement Value | [This document] |
| 9 | Loopback Delay Measurement Min/Max Values | [This document] |
| 10 | Loopback Delay Variation Measurement Value | [This document] |

### 13.4.2. LOSS-MEASUREMENT Object-Types

IANA is requested to create a "LOSS-MEASUREMENT Object-Types" sub-registry for the LOSS-MEASUREMENT Object (Object-class TBD10).

This document defines the following object-types:

| Object-Type | Name | Reference |
|---|---|---|
| 0 | Reserved | [This document] |
| 1 | Loss Measurement Status | [This document] |
| 2 | Tx Packets-Lost | [This document] |
| 3 | Rx Packets-Lost | [This document] |
| 4 | Total Packets-Sent-Received | [This document] |

### 13.4.3. BANDWIDTH Object-Type

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

| Object-Type | Name | Reference |
|---|---|---|
| TBD12 | BANDWIDTH-UTILIZATION Object | [This document] |

## 13.5. PCE Error Codes

This document defines two new error-values for PCErr with error-code 19 (Invalid Operation). IANA is requested to make the following allocations.

| Error-Value | Name | Reference |
|---|---|---|
| TBD21 | Delay-Measurement capability was not advertised | [This document] |
| TBD22 | Loss-Measurement capability was not advertised | [This document] |
| TBD23 | Two-Way Measurement capability was not advertised | [This document] |
| TBD24 | One-Way Measurement capability was not advertised | [This document] |
| TBD25 | Loopback Measurement capability was not advertised | [This document] |
| TBD26 | Inferred Mode Loss Measurement capability was not advertised | [This document] |
| TBD27 | Direct Mode Loss Measurement capability was not advertised | [This document] |
| TBD28 | Bandwidth Utilization capability was not advertised | [This document] |
| TBD29 | Liveness Detection capability was not advertised | [This document] |

### 13.6. Notification Object Types

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

| Notification-type | Name | Reference |
|---|---|---|
| TBD13 | LSP Measurement Notification | [This document] |
| TBD14 | PM Overwhelm State | [This document] |

Notification-value=1: Entering PM overwhelm state
Notification-value=2: Clearing PM overwhelm state

## 14. References

### 14.1. Normative References

[I-D.ietf-pce-multipath]
Koldychev, M. and S. Sidor, "Path Computation Element Communication Protocol (PCEP) Extensions for Signaling Multipath Information", Work in Progress, Internet-Draft, draft-ietf-pce-multipath-23, 1 April 2026, <https://datatracker.ietf.org/doc/html/draft-ietf-pce-multipath-23>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC3031] Rosen, E., Viswanathan, A., and R. Callon, "Multiprotocol Label Switching Architecture", RFC 3031, DOI 10.17487/RFC3031, January 2001, <https://www.rfc-editor.org/info/rfc3031>.

[RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol (PCEP)", RFC 5440, DOI 10.17487/RFC5440, March 2009, <https://www.rfc-editor.org/info/rfc5440>.

[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>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8231] Crabbe, E., Minei, I., Medved, J., and R. Varga, "Path Computation Element Communication Protocol (PCEP) Extensions for Stateful PCE", RFC 8231, DOI 10.17487/RFC8231, September 2017, <https://www.rfc-editor.org/info/rfc8231>.

[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>.

[RFC9603] Li, C., Ed., Kaladharan, P., Sivabalan, S., Koldychev, M., and Y. Zhu, "Path Computation Element Communication Protocol (PCEP) Extensions for IPv6 Segment Routing", RFC 9603, DOI 10.17487/RFC9603, July 2024, <https://www.rfc-editor.org/info/rfc9603>.

## 14.2. Informative References

[I-D.ietf-spring-stamp-srpm-mpls] Gandhi, R., Filsfils, C., Janssens, B., Chen, M., and R. F. Foote, "Performance Measurement Using Simple Two-Way Active Measurement Protocol (STAMP) for Segment Routing

over the MPLS Data Plane", Work in Progress, Internet-Draft, draft-ietf-spring-stamp-srpm-mpls-01, 2 April 2026, <https://datatracker.ietf.org/doc/html/draft-ietf-spring-stamp-srpm-mpls-01>.

[I-D.ietf-spring-stamp-srpm-srv6]
Gandhi, R., Filsfils, C., Janssens, B., Chen, M., and R. F. Foote, "Performance Measurement Using Simple Two-Way Active Measurement Protocol (STAMP) for Segment Routing over the IPv6 (SRv6) Data Plane", Work in Progress, Internet-Draft, draft-ietf-spring-stamp-srpm-srv6-01, 2 April 2026, <https://datatracker.ietf.org/doc/html/draft-ietf-spring-stamp-srpm-srv6-01>.

[IEEE.754.1985]
IEEE, "IEEE Standard for Binary Floating-Point Arithmetic", IEEE ANSI/IEEE 754-1985, DOI 10.1109/IEEESTD.1985.82928, 5 April 2019, <https://ieeexplore.ieee.org/document/30711>.

[RFC4655] Farrel, A., Vasseur, J.-P., and J. Ash, "A Path Computation Element (PCE)-Based Architecture", RFC 4655, DOI 10.17487/RFC4655, August 2006, <https://www.rfc-editor.org/info/rfc4655>.

[RFC5357] Hedayat, K., Krzanowski, R., Morton, A., Yum, K., and J. Babiarz, "A Two-Way Active Measurement Protocol (TWAMP)", RFC 5357, DOI 10.17487/RFC5357, October 2008, <https://www.rfc-editor.org/info/rfc5357>.

[RFC5925] Touch, J., Mankin, A., and R. Bonica, "The TCP Authentication Option", RFC 5925, DOI 10.17487/RFC5925, June 2010, <https://www.rfc-editor.org/info/rfc5925>.

[RFC6374] Frost, D. and S. Bryant, "Packet Loss and Delay Measurement for MPLS Networks", RFC 6374, DOI 10.17487/RFC6374, September 2011, <https://www.rfc-editor.org/info/rfc6374>.

[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, DOI 10.17487/RFC7420, December 2014, <https://www.rfc-editor.org/info/rfc7420>.

[RFC7471] Giacalone, S., Ward, D., Drake, J., Atlas, A., and S. Previdi, "OSPF Traffic Engineering (TE) Metric Extensions", RFC 7471, DOI 10.17487/RFC7471, March 2015, <https://www.rfc-editor.org/info/rfc7471>.

[RFC7823] Atlas, A., Drake, J., Giacalone, S., and S. Previdi, "Performance-Based Path Selection for Explicitly Routed Label Switched Paths (LSPs) Using TE Metric Extensions", RFC 7823, DOI 10.17487/RFC7823, May 2016, <https://www.rfc-editor.org/info/rfc7823>.

[RFC8233] Dhody, D., Wu, Q., Manral, V., Ali, Z., and K. Kumaki, "Extensions to the Path Computation Element Communication Protocol (PCEP) to Compute Service-Aware Label Switched Paths (LSPs)", RFC 8233, DOI 10.17487/RFC8233, September 2017, <https://www.rfc-editor.org/info/rfc8233>.

[RFC8253] Lopez, D., Gonzalez de Dios, O., Wu, Q., and D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", RFC 8253, DOI 10.17487/RFC8253, October 2017, <https://www.rfc-editor.org/info/rfc8253>.

[RFC8408] Sivabalan, S., Tantsura, J., Minei, I., Varga, R., and J. Hardwick, "Conveying Path Setup Type in PCE Communication Protocol (PCEP) Messages", RFC 8408, DOI 10.17487/RFC8408, July 2018, <https://www.rfc-editor.org/info/rfc8408>.

[RFC8570] Ginsberg, L., Ed., Previdi, S., Ed., Giacalone, S., Ward, D., Drake, J., and Q. Wu, "IS-IS Traffic Engineering (TE) Metric Extensions", RFC 8570, DOI 10.17487/RFC8570, March 2019, <https://www.rfc-editor.org/info/rfc8570>.

[RFC8571] Ginsberg, L., Ed., Previdi, S., Wu, Q., Tantsura, J., and C. Filsfils, "BGP - Link State (BGP-LS) Advertisement of IGP Traffic Engineering Performance Metric Extensions", RFC 8571, DOI 10.17487/RFC8571, March 2019, <https://www.rfc-editor.org/info/rfc8571>.

[RFC8664] Sivabalan, S., Filsfils, C., Tantsura, J., Henderickx, W., and J. Hardwick, "Path Computation Element Communication Protocol (PCEP) Extensions for Segment Routing", RFC 8664, DOI 10.17487/RFC8664, December 2019, <https://www.rfc-editor.org/info/rfc8664>.

[RFC8733] Dhody, D., Ed., Gandhi, R., Ed., Palle, U., Singh, R., and L. Fang, "Path Computation Element Communication Protocol (PCEP) Extensions for MPLS-TE Label Switched Path (LSP)

Auto-Bandwidth Adjustment with Stateful PCE", RFC 8733, DOI 10.17487/RFC8733, February 2020, <https://www.rfc-editor.org/info/rfc8733>.

[RFC8762] Mirsky, G., Jun, G., Nydell, H., and R. Foote, "Simple Two-Way Active Measurement Protocol", RFC 8762, DOI 10.17487/RFC8762, March 2020, <https://www.rfc-editor.org/info/rfc8762>.

[RFC9779] Gandhi, R., Ed., Filsfils, C., Voyer, D., Salsano, S., and M. Chen, "Performance Measurement for Segment Routing Networks with the MPLS Data Plane", RFC 9779, DOI 10.17487/RFC9779, May 2025, <https://www.rfc-editor.org/info/rfc9779>.

[RFC9826] Dhody, D., Ed., Beeram, V., Hardwick, J., and J. Tantsura, "A YANG Data Model for the Path Computation Element Communication Protocol (PCEP)", RFC 9826, DOI 10.17487/RFC9826, September 2025, <https://www.rfc-editor.org/info/rfc9826>.

## Appendix A. Example Use Cases

This section describes a non-exhaustive list of examples of deployment use cases of PM for LSPs when deployed in a network with the PCE. A Network Management System (NMS) may also be deployed in the network capable of receiving and processing streaming telemetry of PM metrics and may interact with the PCC and PCE for the PM as described in use cases 3, 4, and 5.

Use case 1: PCE Enables PM on the PCC and PCC Takes Action

PCE -----> PCC

In this use case, the PCE sets the upper bound threshold condition for LSPs at the PCC. The PCC takes a local action when the condition is met. The action could be based on a local policy or a policy set by the PCE. The steps involved are -

* PCE sends the PM attributes as part of the PCE-initiated LSPs including an upper bound threshold (Section 4.8 in this document) for the PM metrics using the PCEP extensions defined in this document.

* PCC takes actions when PM metrics exceed the upper bound threshold. Such actions could include bringing down the LSP, triggering a protection switch-over, removing the LSP from IGP for some prefixes, or requesting a new path from the PCE (based on

local policies that may be set by the PCE). PCC may take these actions even when LSPs are delegated to the PCE as the upper bound is set by the PCE.

* PCC does not report the PM metrics to the PCE.

* PCC may install the new LSP in the routing table only if the PM metric is below the upper bound; otherwise, the PCC may reject the LSP request and send an error to the PCE.

* The report interval should be set to 0 to disable reporting to the PCE. Only the upper bound threshold should be set.

Use case 2: PCC Reports PM Metrics to the PCE, PCE Takes Action

PCE <----- PCC

In this use case, the PCC reports the PM metrics and parameters to the PCE and the PCE may take an immediate local (reactive) action based on the PM metrics. The steps involved are -

* PCC sends the PM metrics and parameters to the PCE using the PCEP extensions defined in this document and the PCE takes an action; actions could be to correlate faults, invalidate the LSP path, send new LSP path to the PCC (trigger re-optimization), etc.

* If an upper bound threshold is set, the PCC only reports the PM metrics to the PCE when the upper bound is crossed. Otherwise, the PCC reports the PM metrics to the PCE every report-interval.

* Optionally, the PCC may take an immediate local (reactive) action such as triggering a path protection switch-over when PM metrics exceed the upper bound.

* The PCE has a global view due to PM metric reports received from various PCCs and hence can make a better decision about LSP placement in the network.

* The PCE can make proactive decisions based on PM metrics when metrics are reported before the crossing of the upper bound as opposed to a reactive action that the PCC could make.

* The report interval should be set to enable reporting by the PCC. Optionally, the upper bound threshold may also be set.

Use case 3: PCE Enables PM on the PCC, PCC Sends PM Metrics to NMS

PCE -----> PCC -----> NMS

The steps involved are -

* An NMS may be used in a network that is capable of streaming telemetry for receiving data and Yang or XML-based provisioning using a non-PCEP channel. The NMS may interact with a PCE for LSP path computation using the PCEP channel.

* PCE sends the PM attributes as part of PCE-initiated LSPs using the PCEP extensions defined in this document.

* PCC reports the PM metrics to the NMS via streaming telemetry.

* The NMS may request the PCE to take an action based on the PM metrics.

* The report interval should be set to 0 to disable reporting to the PCE. The other PM attributes may be set and used for streaming telemetry.

Use case 4: NMS Enables PM on the PCC, PCC Sends PM Metrics to the PCE

PCE <----- PCC <----- NMS

The steps involved are -

* The NMS enables PM on the PCC using a non-PCEP channel.

* The PCC then reports the PM metrics to the PCE using the PCEP extensions defined in this document.

* The PCE may take an action based on the PM metrics received from the PCC.

Use case 5: NMS Enables PM on the PCC, PCC Sends PM Metrics to NMS

PCE ----> PCC <-----> NMS -----> PCE

The steps involved are -

* The NMS enables PM on the PCC using a non-PCEP channel.

* The PCC reports the PM metrics to the NMS via streaming telemetry.

* The NMS may request the PCE to take an action based on the PM metrics.

* The PCEP extensions defined in this document are not used in this use case.

## Acknowledgments

TBA.

## Authors' Addresses

Rakesh Gandhi
Cisco Systems, Inc.
Canada
Email: rgandhi@cisco.com

Bin Wen
Comcast
Email: Bin_Wen@cable.comcast.com

Colby Barth
HPE
Email: jonathan.barth@hpe.com

Dhruv Dhody
Huawei Technologies
India
Email: dhruv.ietf@gmail.com

Andrew Stone
Nokia
Canada
Email: andrew.stone@nokia.com