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# Path Computation Based on Precision Availability Metrics
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## Abstract

The Path Computation Element (PCE) is able of determining paths according to constraints expressed in the form of metrics. The value of the metric can be signaled as a bound or maximum, meaning that path metric must be less than or equal such value. While this can be sufficient for certain services, some others can require the utilization of Precision Availability Metrics (PAM). This document defines a new object, namely the PRECISION METRIC object, to be used for path calculation or selection for networking services with performance requirements expressed as Service Level Objectives (SLO) using PAM.

## Status of This Memo



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# 1. Introduction

The Path Computation Element (PCE) [RFC4655] is able of determining paths according to constraints expressed in the form of metrics. For that purpose, the METRIC object is defined in [RFC5440]. The value of the metric included in the METRIC object can be signaled as a bound or maximum, meaning that path metric must be less than or equal such value.

While this can be sufficient for certain services, some others can require the utilization of Precision Availability Metrics (PAM) [RFC9544]. That is the case of services like Network Slice [RFC9543] or deterministic [RFC8578] [RFC8655] services. These networking services express their performance requirements by means of Service Level Objectives (SLO) with target values for certain metrics.

At the time of calculating a path by the PCE, the METRIC object [RFC5440] serves for the purposes of indicating either the metric that MUST be optimized by the path computation algorithm, or a bound on the path cost that MUST NOT be exceeded for the path to be considered as acceptable. The value of the metric refers to the instantaneous observed behavior of that parameter, without a notion of behavior along the preceding time. This cannot be sufficient for certain networking services which require to experience stable behavior along the time according to their SLOs.

The precision availability metrics indicate whether or not a given service has been available according to expectations along the time, for whatever SLO considered as constraint. Thus, at the time of computing a path for networking services described by means of SLOs, it is convenient to express the applicable metric constraints according to the definition of precision availability metrics. This permits the PCE to calculate paths showing a behavior compatible to the desired SLOs over a period. This document defines new object, namely the PRECISION METRIC object, using PAM for that purpose.

# 2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT","SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

In addition, the terms defined in [RFC9544] are also used in this document.

## 3. Rationale of the usage of PAM for path calculation

### 3.1. Dynamic behavior of performance parameters

[RFC9544] introduced the concept of intervals for measuring the behavior of measurable performance parameters against some predefined thresholds. Those intervals consider a given time window. Thus, it is possible to define a Violated Interval (VI) as the time interval during which at least one of the performance parameters presents degradation respect to a predefined optimal level threshold. Similarly, when the threshold is defined as critical, the degradation of the performance parameter in a time window generates a Severe Violated Interval (SVI).

Taking into account the VIs and SVIs it is feasible to generate availability metrics showing some degree of historic behavior in the form of the following ratios:

* Violated Interval Ratio (VIR), defined as the ratio of the summed numbers of VIs and SVIs to the total number of time unit intervals along a predefined availability period.

* Severely Violated Interval Ratio (SVIR), defined as the ratio of SVIs to the total number of time unit intervals along a predefined availability period.

At the time of provisioning a networking service which requires stable SLOs along the time, it is important to ensure that the selected path has shown such stable behavior in the past. Despite the fact that the past behavior is not a guarantee of future behavior, it can be presumed that those paths with lower VIR and SVIR will better satisfy the SLOs of the networking service. Alternatively, PAM can be used by the path computation entity for fine-grained path computation. Then PAM is a useful criteria for calculating and selecting paths.

### 3.2. Applicability

Three situations of applicability of precision metrics can be identified:

* The provision of a path according to the desired behavior along the time. In this scenario different segments of a potential path could be monitored before the path is created. The path calculation can take into consideration the measured characteristics of the segments forming that path for decision.

* The selection of a path according to its long-run characteristics. In this scenario, an existing path being monitored along the time can be selected if its behavior is compliant with the long-run behavior expected by the customer.

* The triggering of corrective actions for a selected path. It could be the case that a selected path suffers degradation. The precision metrics can assist on the identification of such potential problems, e.g, raising incidents or anomalies to operational groups, as described in [I-D.ietf-nmop-network-incident-yang].

### 3.3. Usage of collected metrics

The Traffic Engineering Database (TED) defined in [RFC4655] could be considered as the component providing the precision metrics of interest.

The TED stores information related to the network topology, including nodes, links, link attributes (e.g., bandwidth, delay), and any constraints relevant for traffic engineering. It is dynamically updated with information received via routing protocols (e.g., OSPF-TE, IS-IS-TE), ensuring the PCE has up-to-date knowledge. It is also possible to define policies like administrative group (coloring), to be used used in constraint-based path computation.

In order to support precision metrics, the TED could be extended to support e.g. time-series storage and processing capabilities (e.g., to derive histograms from them, as described for instance in Appendix A). The metrics could be gathered from in-band telemetry, active probing mechanisms, or streaming telemetry via standardized interfaces, as complementary information sources to the information received from routing protocols.

Assuming that capability, the PCE queries the TED for compliance with precision constraints.

```
                                                  - Topology
            Path computation request              - Single value metrics
               based on PAM metrics               - Precision metrics
    +-------------+         +-------------+         +-------------+
    |     Path    |         |     Path    |         |   Traffic   |
    | Computation |<------->| Computation |<------->| Engineering |
    |    Client   |         |   Element   |         |  Database   |
    +-------------+         +-------------+         +-------------+
                                                           ^
                                                           |
                                                           v
                                                    +-------------+
                                                    |    Data     |
                                                    |   Sources   |
                                                    +-------------+
                                                 - Link state info
                                                 - Active Probes
                                                 - Streaming telemetry
                                                 - In-band OAM
                                                 - etc
```

Figure 1: Usage of precision metrics stored in TED

The implementation of the TED and its support to the collection, processing and generation of the precision metrics is out of scope of this document.

### 3.4. Calculation or selection of the path

For a given metric, i.e. metric X, it is defined a frequency of values per bin for such a metric (e.g., if the metric refers to latency, a way of expressing it could be to consider the latency below 20 ms the 90% of the time, and below 25 ms the 99% of the time). Thus, the calculation or selection of a path for such a metric X will consist on the comparison of the frequency of the metric values per bin, so that the intended path behaves equal or better than the intended path. For that purpose, the statistical behavior of the path is characterized e.g. as described in Appendix A.

## 4. PRECISION METRIC Object

## 4.1. Motivation for a new object to express precision metrics

The existing METRIC object [RFC5440] is used to specify either the metric that the path computation algorithm MUST optimize or a constraint on the path cost (i.e., an upper bound) that MUST NOT be exceeded for the path to be deemed acceptable. A number of metric types to be used in the METRIC object have been already defined in IANA registries [IANA_METRIC_Object].

There are several reasons for proposing the definition of a new object for dealing with precision metrics instead of forcing the augmentation of the existing METRIC object:

* The notion of precision metric refers to the fact on how the metric is described, that is, in terms of tiers constituting a statistical distribution of the metric of interest. This implies that the metric type does not change if the metric is expressed as precision metric or not. Then extending the type in the METRIC object for including the notion of precision can create inconsistencies.

* Not all the existing metric types currently defined for the METRIC object could (easily) adhere to the notion of precision metrics (e.g., number of layers on a path).

* The current structure of the METRIC object is not sufficiently flexible for permitting a clean description of the precision metrics.

* The precision metrics can be independent of the existing metric in the METRIC object, and can be implemented simultaneously or separately.

The former limitations make preferable the introduction of a new object facilitating a lean design for the way of expressing precision metrics at the time of performing path calculations with the PCE.

## 4.2. Definition of the PRECISION METRIC Object

The PRECISION METRIC object is defined according to the following structure.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags  |C|S|     Type      | Stat Function |     Tiers     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    AvPeriod   |    TI_Units   |          TI_Value             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Violated Interval Ratio                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Severely Violated Interval Ratio                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
~                        Thresholds                             ~
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: PRECISION METRIC object

The following fields are defined.

* From the Flags field, two flags are defined in this document.

  o S flag (Statistical - 1 bit): determines if the metric follows a statistical distribution function. When S=0, it means that the metric will be assessed against an optimal (for VI) and a critical (for SVI) thresholds. When S=1, it means that the metric will be assessed against a multi-tiered SLO, presenting different thresholds per tier. In case the SLO is defined in N tiers, each tier is associated with a threshold. Following the example in [RFC9544], a latency metric defined in this way could be expressed in the form of

    + not to exceed 30 ms for any packet;
    + to not exceed 25 ms for 99.999% of packets;
    + to not exceed 20 ms for 99% of packets.

  o C (Computed Metric - 1 bit), with similar meaning and implications to the C flag defined on the METRIC object in [RFC5440]. That is, when C=1 in a PCReq message it indicates that the PCE MUST provide the computed path precision metric value in the PCRep message.

  o Unassigned flags MUST be set to zero on transmission and MUST be ignored on receipt.

* Type (8 bits): specifies the metric type. The valid metric type values are those allocated by IANA for the original METRIC object T field.

(Note. To check with PCE WG if this is the correct approach, or if alternatively it is convenient to allocate specific values for the PRECISION METRIC object).

* Stat Function field (8 bits): in case S=1, this field determines the statistical function for describing the SLO. The following functions are considered:

  - 0x0: this is a reserved value.
  - 0x1: histogram
  - 0x2: cumulative distribution function
  - 0x3 - 0x255: these are reserved for future use.

  When S=0, this field SHOULD be ignored.

* Tiers (8 bits): determines the number of tiers in which the statistical distribution of the SLO is defined. The following values are considered:

  - 0x0-0x1: these are invalid values.
  - 0x2: two tiers, valid for the case S=0.
  - 0x3- 0x255: multiple tiers, valid for the case S=1.

* AvPeriod (Availability Period - 8 bits): specifies the total number of time unit intervals to be considered for the calculation of VIR and SVIR shown by the path.

* TI_Units (Time Interval Units - 8 bits): specifies the units for the definition of the time window of the interval. The following units are considered:

  - 0x0: this is a reserved value.
  - 0x1: microsecond
  - 0x2: millisecond
  - 0x3: second
  - 0x4: minute
  - 0x5: hour
  - 0x6: day
  - 0x7: week
  - 0x8: month
  - 0x9: year
  - 0x10 - 0x255: these are reserved for future use.

A PRECISION METRIC Object with values 0x0 or 0x1 SHOULD be discarded. A PRECISION METRIC Object with S=0 and Tiers field different than 0x2 SHOULD be discarded. This value implies that the Threshold field will be composed by an Optimal Threshold (for VI) and a Critical Threshold (for SVI). Finally, a PRECISION METRIC Object with S=1 and Tiers field lower than 0x3 SHOULD be discarded. When a generic value of N is provided in this field, it implies that the Threshold field will be compose by N-1 thresholds (for VI per tier) and a Critical Threshold (for SVI corresponding to the highest tier).

* TI_Value (Time Interval Value - 16 bits): specifies the numerical value for the definition of the time window of the interval.

* Violated Interval Ratio (32 bits): specifies the expected VIR for the path, encoded in 32 bits in IEEE floating point format [IEEE.754.2019]. The VIR of the path calculated by the PCE SHOULD be lower or equal than this value. The way in which the PCE calculates the VIR is out of scope of this document.

* Severely Violated Interval Ratio (32 bits): specifies the expected SVIR for the path, encoded in 32 bits in IEEE floating point format [IEEE.754.2019]. The SVIR of the path calculated by the PCE SHOULD be lower or equal than this value. The way in which the PCE calculates the SVIR is out of scope of this document.

Regarding the Thresholds field, this will be variable in size depending on the statistical nature of the precision metric. When the metric is defined only according to an optimal and critical thresholds (S=0 case), then only those thresholds are included in the field. However, when the SLO is defined by means of a multi-tiered statistical distribution (S=1 case), then one threshold field is included per tier. In summary, this would be the different possible situations for the Thresholds field:

* S=0, meaning that only an optimal and critical thresholds are considered. In this case, the Thresholds field follows the following structure:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Optimal Threshold Tier Boundary                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Optimal Threshold                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Critical  Threshold                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Structure of Thresholds field for S=0

The Optimal Threshold Tier Boundary, the Optimal Threshold and the Critical Threshold fields are encoded in 32 bits in IEEE floating point format [IEEE.754.2019].

* S=1, meaning that only an optimal and critical thresholds are considered. In this case, the Thresholds field follows the following structure:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Tier 1 Boundary                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold for Tier 1                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                              ...                              ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Tier N-1 Boundary                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold for Tier N-1                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Critical  Threshold                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Structure of Thresholds field for S=1

All the Threshold fields are encoded in 32 bits in IEEE floating point format [IEEE.754.2019].

The way in which the PCE calculates the different thresholds is out of scope of this document.

### 4.3. Summary of the PRECISION METRIC Object

The PRECISION METRIC Object is extended to take into consideration PAMs. The PRECISION METRIC object is defined to accommodate the expression of constraints following the PAM proposition in [RFC9544].

According to the definition before, and depending on the statistical description of the SLO, two different messages can be found.

When S=0 the SLO or metric is defined against an optimal and a critical thresholds. In consequence, the message format is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags  |C|0|      Type     | Stat Function |      0x2      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    AvPeriod   |    TI_Units   |           TI_Value            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Violated Interval Ratio                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Severely Violated Interval Ratio                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Optimal Threshold Tier Boundary                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Optimal Threshold                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Critical  Threshold                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Complete structure of PRECISION METRIC object for S=0

In this case, the message has a fixed size of 28 bytes.

When S=1 the SLO or metric is defined following an statistical distribution with N tiers, representing a total of N-1 optimal thresholds plus a critical one. In consequence, the message format is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags  |C|1|      Type     | Stat Function |      0xN      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    AvPeriod   |    TI_Units   |          TI_Value             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Violated Interval Ratio                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Severely Violated Interval Ratio                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Tier 1 Boundary                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Threshold for Tier 1                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                              ...                              ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Tier N-1 Boundary                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Threshold for Tier N-1                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Critical  Threshold                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: Complete structure of PRECISION METRIC object for S=1

In this case, the message has a variable size determined by (4+(2N-1))*4 bytes, being N the number of tiers of the SLO statistical distribution.

### 4.4. Examples on the usage of the PRECISION METRIC Object.

#### 4.4.1. PRECISION METRIC coding examples

The following are examples of usage of the PRECISION METRIC Object. Path Delay metric type is used as precision metric in these examples.

The first example assumes a networking service characterized by a SLO defined by means of two tiers with optimal threshold of 20 ms for 99,9% of the packet latency samples, and critical threshold of 25 ms. The availability expectation for this service is to show a VIR of 5% and a SVIR of 0,2%. The availability period considered is one day, while the time interval is considered 1 hour. In these conditions, the extended METRIC Object can be described as:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags  |C|0|  Type = 12    |     n/a       |      0x2      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| AvPeriod= 24  | TI_Units= sec |      TI_Value= 3600           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Violated Interval Ratio=  5                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Severely Violated Interval Ratio= 0.2              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Optimal Threshold Tier Boundary= 99.9              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Optimal Threshold= 20                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Critical  Threshold= 25                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: Example of usage of PRECISION METRIC object with a SLO defined by two tiers

The second example takes the example of statistical distribution in [RFC9544], where the path delay metric is statistically defined in the form of:

- not to exceed 30 ms for any packet;
- to not exceed 25 ms for 99.999% of packets;
    - to not exceed 20 ms for 99% of packets

Assuming similar VIR, SVIR, availability period and time interval duration. In these conditions, he extended METRIC Object can be descrined as:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Flags  |C|1|  Type = 12    | ST= Histogram |      0x3      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| AvPeriod= 24  | TI_Units= sec |      TI_Value= 3600           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Violated Interval Ratio=  5                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Severely Violated Interval Ratio= 0.2              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Tier 1 Boundary= 99.9                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Threshold for Tier 1= 20                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Tier 2 Boundary= 99.999                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Threshold for Tier 1= 25                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Critical  Threshold= 30                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 8: Example of usage of PRECISION METRIC object with a SLO defined by a statistical distribution

Once the PCE processes these PRECISION METRIC Objects, the PCE will calculate the VIR and SVIR of the different path alternatives and check them against the requested VIR and SVIR. How the PCE calculate the VIR and SVIR is out of scope of this document.

### 4.4.2. PRECISION METRIC operation examples

The example considers a PCC sending a path computation request to the PCE, including a PRECISION METRIC object detailing path delay described in terms of SLO, and a METRIC object indicating that the path loss must not exceed the value of M. The two objects are inserted in the PCReq message as follows:

o First PRECISION METRIC object coded as in the previous examples, depending on the applicable SLO.

o Second METRIC object with B=1, T=14, metric-value=M

In case the PRECISION METRIC contains flag C = 1, as per [RFC5440], in case there is a path satisfying the set of constraints and there is no policy that prevents the return of the computed metric, then the PCE inserts in its response one PRECISION METRIC object with T=12 and the corresponding SLO description for that path (i.e., all the fields contained in the definition of the PRECISION METRIC Object). Additionally, the PCE MAY insert a second METRIC object with B=1, T=14, metric-value=computed path loss.

### 4.5. Interaction between precision metric object and the metric object

The precision metric type values in the PRECISION METRIC object are intended to reuse the valid metric type values which are allocated by IANA for the original METRIC object T field. The precision metric object and metric object may be both carried as the constraints for path computing, but they must be set to different type values for valid path requests.

It could be the case that a path request could contain both a METRIC and a PRECISION METRIC objects for the same type of metric, for instance, delay. This behavior can be considered anomalous and, as such, the PCE will send back a PCErr message , for example, a Error-Type "Invalid Operation" and Error-Value "Unsupported Metric Object and PAM metric Object with same type".

## 5. PCEP message extensions

Message formats in this document are expressed using Routing Backus-Naur Form (RBNF). This is an initial attempt for defining the proposed extensions to PCEP messages on top of [RFC8233] definitions.

Note. Further revision of these formats is needed. Consider them as an initial exercise by now.

### 5.1. The PCReq Message

The extension to the PCReq message would be as follows:

* New optional PRECISION METRIC object

* New metric types using the optional PRECISION METRIC object

The format of the PCReq message (with [RFC5541], [RFC8231] and [RFC8233] as a base) is updated as follows:

```
<PCReq Message> ::= <Common Header>
                    [<svec-list>]
                    <request-list>
where:
     <svec-list> ::= <SVEC>
                     [<OF>]
                     [<metric-list>]
                     [<precision-metric-list>]
                     [<svec-list>]

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

     <request> ::= <RP>
                   <END-POINTS>
                   [<LSP>]
                   [<LSPA>]
                   [<BANDWIDTH>]
                   [<bu-list>]
                   [<metric-list>]
                   [<precision-metric-list>]
                   [<OF>]
                   [<RRO>[<BANDWIDTH>]]
                   [<IRO>]
                   [<LOAD-BALANCING>]

and where:
     <precision-metric-list> ::= <PRECISION-METRIC>[<precision-metric-list>]
```

Figure 9: PCReq Message

## 5.2. The PCRep Message

The extension to the PCReq message would be as follows:

* New optional PRECISION METRIC object (during unsuccessful path computation based on precision metrics, to indicate the precision metrics requested which are reason for failure)

* New metric types using the optional PRECISION METRIC object

The format of the PCRep message (with [RFC5541], [RFC8231] and [RFC8233] as a base) is updated as follows:

```
   <PCRep Message> ::= <Common Header>
                       [<svec-list>]
                       <response-list>

   where:

         <svec-list> ::= <SVEC>
                         [<OF>]
                         [<metric-list>]
                         [<precision-metric-list>]
                         [<svec-list>]

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

        <response> ::= <RP>
                       [<LSP>]
                       [<NO-PATH>]
                       [<attribute-list>]
                       [<path-list>]

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

        <path> ::= <ERO>
                   <attribute-list>

   and where:

        <attribute-list> ::= [<OF>]
                             [<LSPA>]
                             [<BANDWIDTH>]
                             [<bu-list>]
                             [<metric-list>]
                             [<precision-metric-list>]
                             [<IRO>]

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

Figure 10: PCRep Message

## 5.3. The PCRpt Message

The PCRpt message can use the updated attribute-list (as extended in previous section) for the purpose of including the PRECISION-METRIC object.

## 6. Security and operational considerations

### 6.1. Security considerations

Same security and operational considerations as described in [RFC5440] apply also in this document.

When a path request could contain both a METRIC and a PRECISION METRIC objects for the same type of metric, the PCE will send back a PCErr message. In order to avoid denial of service attacks, new similar requests could be silently ignored during periods or time, or even requests from the same PCC could be filtered to prevent PCE affection.

Other security considerations will be addressed in future versions of the document.

### 6.2. Operational considerations

The work with precision metrics can impose stringent requirements in terms of collection, processing and assessment of metrics of interest. Such capabilities are expected to be supported by external systems, such as the TED, with the role of the PCE being limited to the work with processed information (e.g., histograms) so to assess that the precision metric used as constraint is compliant with the expectation of the PCC. Such external supportive systems are out of scope of this document.

## 7. IANA Considerations

This document defines a new object class for the PCEP. IANA is requested to allocate the following codepoint in the PCEP "Objects" registry.

| Value | Description | Reference |
|---|---|---|
| TBD1 | PRECISION METRIC object | This document |

Furthermore, the following Error-Type and Error-value of the PCEP Error Object are specified

| Value | Description | Reference |
|---|---|---|
| TBD2 | Error-Type "Invalid Operation" | This document |
| TBD3 | Error Value "Unsupported Metric Object and PAM metric Object with same type" | This document |

Additional IANA considerations required by this extension will be documented in future document versions (for instance, in respect to precision metric types).

# 8. References

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## Appendix A. Path Histogram Composition

In order to obtain the statistical distribution of a metric over a complete path from the corresponding distributions of its constituent segments (e.g., hops) it is necessary to consider the class of the metric under evaluation, i.e., if the metric is additive, multiplicative, or maximal/minimal.

### A.1. Additive Metrics

Additive metrics are those that sum along the path, such as delay or IGP cost [RFC4655], [RFC8233]. To generate a path histogram from segment histograms, the total path value can be obtained by summing the individual segment values along a period, and then forming the histogram.

Alternatively, considering that a histogram is divided into discrete bins representing value ranges, it is possible to perform a bin-by-bin summation. The histogram for the path is then obtained by summing the bin values across the segments.

### A.2. Multiplicative Metrics

Multiplicative metrics, for example link availability or success probability [RFC8233], combine along a path by multiplying segment (e.g., per hop) values. The path histogram can be obtained by combining the segment values and computing the product for each combination.

Alternatively, logarithmic transformation can be applied to convert multiplicative aggregation into additive form, enabling reuse of additive histogram composition techniques. In this method, the values of each histogram bin are transformed by taking the logarithm, effectively converting multiplication into addition. The histograms can then be combined by summing the log-transformed bin values across segments, using the values of each bin per segment to calculate the resulting distribution. After aggregating the histograms in the log domain, the path histogram can be transformed back to the original metric domain by applying the exponential function, yielding the final probabilities for the multiplicative path values.

### A.3. Maximization / Minimization Metrics (Bottleneck Metrics)

Bottleneck metrics are defined by taking the maximum or minimum value along the path, such as bandwidth, MTU, etc [RFC4655]. To construct a path histogram, the values of each segment are considered to build the cumulative distribution function (CDF) of the path.

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