ALTO Working Group   Q. Wu
Internet-Draft   Huawei
Intended status: Standards Track   Y. Yang
Expires: 22 September 2022   Yale University
                                                              Y. Lee
                                                              Samsung
                                                              D. Dhody
                                                              Huawei
                                                       S. Randriamasy
                                                      Nokia Bell Labs
                                                        L. Contreras
                                                            Telefonica
                                                         21 March 2022

ALTO Performance Cost Metrics
draft-ietf-alto-performance-metrics-28

Abstract

   The cost metric is a basic concept in Application-Layer Traffic
   Optimization (ALTO), and different applications may use different
   types of cost metrics. Since the ALTO base protocol (RFC 7285)
   defines only a single cost metric (namely, the generic "routingcost"
   metric), if an application wants to issue a cost map or an endpoint
   cost request in order to identify a resource provider that offers
   better performance metrics (e.g., lower delay or loss rate), the base
   protocol does not define the cost metric to be used.

   This document addresses this issue by extending the specification to
   provide a variety of network performance metrics, including network
   delay, delay variation (a.k.a, jitter), packet loss rate, hop count,
   and bandwidth.

   There are multiple sources (e.g., estimation based on measurements or
   service-level agreement) to derive a performance metric. This
   document introduces an additional "cost-context" field to the ALTO
   "cost-type" field to convey the source of a performance metric.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

   Application-Layer Traffic Optimization (ALTO) provides a means for
   network applications to obtain network information so that the
   applications can identify efficient application-layer traffic
   patterns using the networks. Cost metrics are used in both the ALTO
   cost map service and the ALTO endpoint cost service in the ALTO base
   protocol [RFC7285].

Since different applications may use different cost metrics, the ALTO base protocol introduces an ALTO Cost Metric Registry (Section 14.2 of [RFC7285]) as a systematic mechanism to allow different metrics to be specified. For example, a delay-sensitive application may want to use latency related metrics, and a bandwidth-sensitive application may want to use bandwidth related metrics. However, the ALTO base protocol has registered only a single cost metric, i.e., the generic "routingcost" metric (Section 14.2 of [RFC7285]); no latency or bandwidth related metrics are defined in the base protocol.

This document registers a set of new cost metrics (Table 1) to allow applications to determine "where" to connect based on network performance criteria including delay and bandwidth related metrics.

Metric	Definition in this doc	Semantics Based On
One-way Delay	Section 4.1	Base: [RFC7471,8570,8571] sum Unidirectional Delay
Round-trip Delay	Section 4.2	Base: Sum of two directions from above
Delay Variation	Section 4.3	Base: [RFC7471,8570,8571] sum of Unidirectional Delay Variation
Loss Rate	Section 4.4	Base: [RFC7471,8570,8571] aggr Unidirectional Link Loss
Residual Bandwidth	Section 5.2	Base: [RFC7471,8570,8571] min Unidirectional Residual BW
Available Bandwidth	Section 5.3	Base: [RFC7471,8570,8571] min Unidirectional Avail. BW
TCP Throughput	Section 5.1	[I-D.ietf-tcpm-rfc8312bis]
Hop Count	Section 4.5	[RFC7285]

Table 1. Cost Metrics Defined in this Document.

The first 6 metrics listed in Table 1 (i.e., One-way Delay, Round-trip Delay, Delay Variation, Loss Rate, Residual Bandwidth, and Available Bandwidth) are derived from the set of traffic engineering performance metrics commonly defined in OSPF [RFC3630], [RFC7471]; IS-IS [RFC5305], [RFC8570]; and BGP-LS [RFC8571]. Deriving ALTO cost performance metrics from existing network-layer traffic engineering performance metrics, to expose to application-layer traffic optimization, can be a typical mechanism by network operators to deploy ALTO [RFC7971], [FlowDirector]. This document defines the base semantics of these metrics by extending them from link metrics

to end-to-end metrics for ALTO. The "Semantics Based On" column
specifies at a high level how the end-to-end metric is computed from
link metrics; the details will be specified in the following
sections.

The common metrics Min/Max Unidirectional Delay defined in
[RFC8570][RFC8571] and Max Link Bandwidth defined in
[RFC3630,RFC5305] are not listed in Table 1 because they can be
handled by applying the statistical operators defined in this
document. The metrics related with utilized bandwidth and reservable
bandwidth (i.e., Max Reservable BW and Unreserved BW defined in
[RFC3630,RFC5305]) are outside the scope of this document.

The 7th metric (the estimated TCP-flow throughput metric) provides an
estimation of the bandwidth of a TCP flow, using TCP throughput
modeling, to support use cases of adaptive applications [Prophet],
[G2]. Note that other transport-specific metrics can be defined in
the future. For example, QUIC-related metrics [RFC9000] can be
considered when the methodology to measure such metrics is more
mature (e.g., [I-D.corre-quic-throughput-testing]).

The 8th metric (the hop count metric) in Table 1 is mentioned in the
ALTO base protocol [RFC7285], but not defined, and this document
defines it to be complete.

These 8 performance metrics can be classified into two categories:
those derived from the performance of individual packets (i.e., One-
way Delay, Round-trip Delay, Delay Variation, Loss Rate, and Hop
Count), and those related to bandwidth/throughput (Residual
bandwidth, and Available Bandwidth, and TCP throughput). These two
categories are defined in Sections 4 and 5 respectively. Note that
all metrics except Round-trip Delay are unidirectional. An ALTO
client will need to query both directions if needed.

The purpose of this document is to ensure proper usage of these 8
performance metrics in the context of ALTO. This document follows
the guideline defined in Section 14.2 of the ALTO base protocol
[RFC7285] on registering ALTO cost metrics. Hence, it specifies the
identifier, the intended semantics, and the security considerations
of each one of the metrics specified in Table 1.

The definitions of the intended semantics of the metrics tend to be
coarse-grained, for guidance only, and they may work well for ALTO.
On the other hand, a performance measurement framework, such as the
IP Performance Measurement (IPPM) framework, may provide more details
in defining a performance metric. This document introduces a
mechanism called "cost-context" to provide additional details, when
they are available; see Section 3.

Following the ALTO base protocol, this document uses JSON to specify
the value type of each defined metric. See [RFC8259] for JSON data
type specification. In particular, [RFC7285] specifies that cost
values should be assumed by default as JSONNumber. When defining the
value representation of each metric in Table 1, this document
conforms to [RFC7285], but specifies additional, generic constraints
on valid JSONNumbers for each metric. For example, each new metric
in Table 1 will be specified as non-negative (>= 0); Hop Count is
specified to be an integer.

An ALTO server may provide only a subset of the metrics described in
this document. For example, those that are subject to privacy
concerns should not be provided to unauthorized ALTO clients. Hence,
all cost metrics defined in this document are optional; not all of
them need to be exposed to a given application. When an ALTO server
supports a cost metric defined in this document, it announces the
metric in its information resource directory (IRD) as defined in
Section 9.2 of [RFC7285].

An ALTO server introducing these metrics should consider related
security issues. As a generic security consideration on the
reliability and trust in the exposed metric values, applications
SHOULD rapidly give up using ALTO-based guidance if they detect that
the exposed information does not preserve their performance level or
even degrades it. Section 7 discusses security considerations in
more detail.

2. 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.

3. Performance Metric Attributes

The definitions of the metrics in this document are coarse-grained,
based on network-layer traffic engineering performance metrics, for
guidance only. A fine-grained framework specified in [RFC6390]
requires that the fine-grained specification of a network performance
metric include 6 components: (i) Metric Name, (ii) Metric
Description, (iii) Method of Measurement or Calculation, (iv) Units
of Measurement, (v) Measurement Points, and (vi) Measurement Timing.
Requiring that an ALTO server provides precise, fine-grained values
for all 6 components for each metric that it exposes may not be
feasible or necessary for all ALTO use cases. For example, an ALTO
server computing its metrics from network-layer traffic-engineering

performance metrics may not have information about the method of
measurement or calculation (e.g., measured traffic patterns).

To address the issue and realize ALTO use cases, for metrics in
Table 1, this document defines performance metric identifiers which
can be used in the ALTO protocol with well-defined (i) Metric Name,
(ii) Metric Description, (iv) Units of Measurement, and (v)
Measurement Points, which are always specified by the specific ALTO
services; for example, endpoint cost service is between the two
endpoints. Hence, the ALTO performance metric identifiers provide
basic metric attributes.

To allow the flexibility of allowing an ALTO server to provide fine-
grained information such as Method of Measurement or Calculation,
according to its policy and use cases, this document introduces
context information so that the server can provide these additional
details.

3.1. Performance Metric Context: "cost-context"

The core additional details of a performance metric specify "how" the
metric is obtained. This is referred to as the source of the metric.
Specifically, this document defines three types of coarse-grained
metric information sources: "nominal", and "sla" (service level
agreement), and "estimation".

For a given type of source, precise interpretation of a performance
metric value can depend on specific measurement and computation
parameters.

To make it possible to specify the source and the aforementioned
parameters, this document introduces an optional "cost-context" field
to the "cost-type" field defined by the ALTO base protocol
(Section 10.7 of [RFC7285]) as the following:

```
    object {
      CostMetric    cost-metric;
      CostMode      cost-mode;
      [CostContext cost-context;]
      [JSONString   description;]
    } CostType;

    object {
      JSONString    cost-source;
      [JSONValue     parameters;]
    } CostContext;
```

"cost-context" will not be used as a key to distinguish among
performance metrics. Hence, an ALTO information resource MUST NOT
announce multiple CostType with the same "cost-metric", "cost-mode"
and "cost-context". They must be placed into different information
resources.

The "cost-source" field of the "cost-context" field is defined as a
string consisting of only US-ASCII alphanumeric characters
(U+0030-U+0039, U+0041-U+005A, and U+0061-U+007A). The cost-source
is used in this document to indicate a string of this format.

As mentioned above, this document defines three values for "cost-
source": "nominal", "sla", and "estimation". The "cost-source" field
of the "cost-context" field MUST be one registered in "ALTO Cost
Source" registry (Section 8).

The "nominal" category indicates that the metric value is statically
configured by the underlying devices. Not all metrics have
reasonable "nominal" values. For example, throughput can have a
nominal value, which indicates the configured transmission rate of
the involved devices; latency typically does not have a nominal
value.

The "sla" category indicates that the metric value is derived from
some commitment which this document refers to as service-level
agreement (SLA). Some operators also use terms such as "target" or
"committed" values. For an "sla" metric, it is RECOMMENDED that the
"parameters" field provide a link to the SLA definition.

The "estimation" category indicates that the metric value is computed
through an estimation process. An ALTO server may compute
"estimation" values by retrieving and/or aggregating information from
routing protocols (e.g., [RFC7471], [RFC8570], [RFC8571]), traffic
measurement management tools (e.g., TWAMP [RFC5357]), and measurement
frameworks (e.g., IPPM), with corresponding operational issues. An
illustration of potential information flows used for estimating these
metrics is shown in Figure 1. Section 6 discusses in more detail the
operational issues and how a network may address them.

```
                +--------+  +--------+  +--------+
                | Client |  | Client |  | Client |
                +----^---+  +---^----+  +---^----+
                     |          |           |
                     +----------|-----------+
                  North-Bound  |ALTO protocol
                  Interface (NBI)|
                             |
                     +--+-----+   retrieval    +----------+
                     |  ALTO  |<---------------|  Routing  |
                     | Server |  and aggregation|          |
                     |        |<------------+  |  Protocols|
                     +--------+             |  +----------+
                                            |
                                            |  +-----------+
                                            |  |Performance|
                                            ---| Monitoring|
                                               |   Tools   |
                                               +-----------+
```
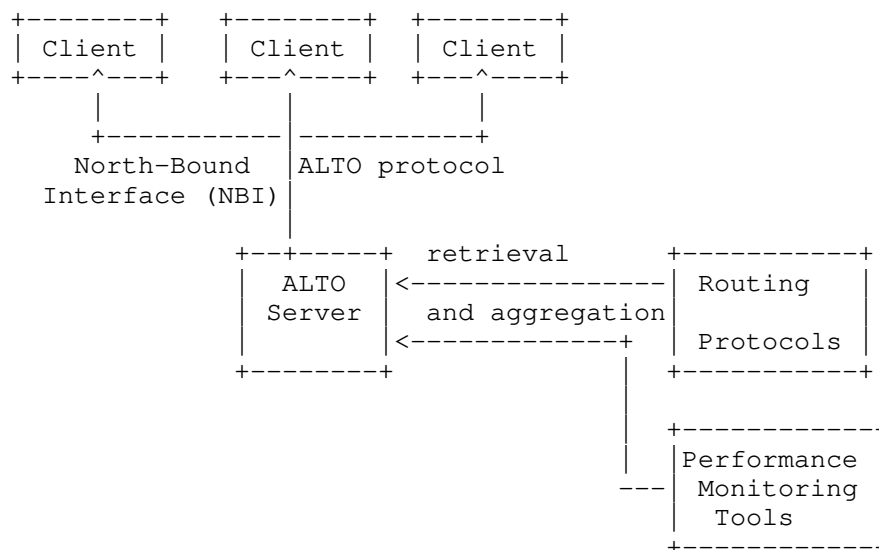
       Figure 1. A framework to compute estimation to performance metrics

       There can be multiple choices in deciding the cost-source category.
       It is the operator of an ALTO server who chooses the category. If a
       metric does not include a "cost-source" value, the application MUST
       assume that the value of "cost-source" is the most generic source,
       i.e., "estimation".

3.2. Performance Metric Statistics

       The measurement of a performance metric often yields a set of samples
       from an observation distribution ([Prometheus]), instead of a single
       value. A statistical operator is applied to the samples to obtain a
       value to be reported to the client. Multiple statistical operators
       (e.g., min, median, and max) are commonly being used.

       Hence, this document extends the general US-ASCII alphanumeric cost
       metric strings, formally specified as the CostMetric type defined in
       Section 10.6 of [RFC7285], as follows:

          A cost metric string consists of a base metric identifier (or base
          identifier for short) string, followed by an optional statistical
          operator string, connected by the ASCII character colon (':',
          U+003A), if the statistical operator string exists. The total
          length of the cost metric string MUST NOT exceed 32, as required
          by [RFC7285].

       The statistical operator string MUST be one of the following:

cur:
   the instantaneous observation value of the metric from the most
   recent sample (i.e., the current value).

percentile, with letter 'p' followed by a number:
   gives the percentile specified by the number following the letter
   'p'. The number MUST be a non-negative JSON number in the range
   [0, 100] (i.e., greater than or equal to 0 and less than or equal
   to 100), followed by an optional decimal part, if a higher
   precision is needed. The decimal part should start with the '.'
   separator (U+002E), and followed by a sequence of one or more
   ASCII numbers between '0' and '9'. Assume this number is y and
   consider the samples coming from a random variable X. Then the
   metric returns x, such that the probability of X is less than or
   equal to x, i.e., Prob(X <= x), = y/100. For example, delay-
   ow:p99 gives the 99% percentile of observed one-way delay; delay-
   ow:p99.9 gives the 99.9% percentile. Note that some systems use
   quantile, which is in the range [0, 1]. When there is a more
   common form for a given percentile, it is RECOMMENDED that the
   common form be used; that is, instead of p0, use min; instead of
   p50, use median; instead of p100, use max.

 min:
    the minimal value of the observations.

 max:
    the maximal value of the observations.

 median:
    the mid-point (i.e., p50) of the observations.

 mean:
    the arithmetic mean value of the observations.

 stddev:
    the standard deviation of the observations.

 stdvar:
    the standard variance of the observations.

Examples of cost metric strings then include "delay-ow", "delay-ow:min", "delay-ow:p99", where "delay-ow" is the base metric identifier string; "min" and "p99" are example statistical operator strings.

If a cost metric string does not have the optional statistical operator string, the statistical operator SHOULD be interpreted as the default statistical operator in the definition of the base metric. If the definition of the base metric does not provide a definition for the default statistical operator, the metric MUST be considered as the median value.

Note that RFC 7258 limits the overall cost metric identifier to 32 characters. The cost metric variants with statistical operator suffixes defined by this document are also subject to the same overall 32-character limit, so certain combinations of (long) base metric identifier and statistical operator will not be representable. If such a situation arises, it could be addressed by defining a new base metric identifier that is an "alias" of the desired base metric, with identical semantics and just a shorter name.

4. Packet Performance Metrics

This section introduces ALTO network performance metrics on one way delay, round-trip delay, delay variation, packet loss rate, and hop count. They measure the "quality of experience" of the stream of packets sent from a resource provider to a resource consumer. The measures of each individual packet (pkt) can include the delay from the time when the packet enters the network to the time when the packet leaves the network (pkt.delay); whether the packet is dropped before reaching the destination (pkt.dropped); the number of network hops that the packet traverses (pkt.hopcount). The semantics of the performance metrics defined in this section are that they are statistics computed from these measures; for example, the x-percentile of the one-way delay is the x-percentile of the set of delays {pkt.delay} for the packets in the stream.

4.1. Cost Metric: One-Way Delay (delay-ow)

4.1.1. Base Identifier

The base identifier for this performance metric is "delay-ow".

4.1.2. Value Representation

The metric value type is a single 'JSONNumber' type value conforming
to the number specification of Section 6 of [RFC8259]. The unit is
expressed in microseconds. Hence, the number can be a floating point
number to express delay that is smaller than microseconds. The
number MUST be non-negative.

4.1.3. Intended Semantics and Use

Intended Semantics: To specify the temporal and spatial aggregated
delay of a stream of packets from the specified source to the
specified destination. The base semantics of the metric is the
Unidirectional Delay metric defined in [RFC8571,RFC8570,RFC7471], but
instead of specifying the delay for a link, it is the (temporal)
aggregation of the link delays from the source to the destination. A
non-normative reference definition of end-to-end one-way delay is
[RFC7679]. The spatial aggregation level is specified in the query
context, e.g., provider-defined identifier (PID) to PID, or endpoint
to endpoint, where PID is defined in Section 5.1 of [RFC7285].

Use: This metric could be used as a cost metric constraint attribute
or as a returned cost metric in the response.

Example 1: Delay value on source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 239
Content-Type: application/alto-endpointcostparams+json
Accept:
  application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "delay-ow"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}
```

```
HTTP/1.1 200 OK
Content-Length: 247
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "delay-ow"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":    10,
      "ipv4:198.51.100.34": 20
    }
  }
}
```

Note that since the "cost-type" does not include the "cost-source"
field, the values are based on "estimation". Since the identifier
does not include the statistical operator string component, the
values will represent median values.

Example 1a below shows an example that is similar to Example 1, but
for IPv6.

   Example 1a: Delay value on source-destination endpoint pairs for IPv6

```
   POST /endpointcost/lookup HTTP/1.1
   Host: alto.example.com
   Content-Length: 252
   Content-Type: application/alto-endpointcostparams+json
   Accept:
     application/alto-endpointcost+json,application/alto-error+json

   {
     "cost-type": {
       "cost-mode":   "numerical",
       "cost-metric": "delay-ow"
     },
     "endpoints": {
       "srcs": [
         "ipv6:2001:db8:100::1"
       ],
       "dsts": [
         "ipv6:2001:db8:100::2",
         "ipv6:2001:db8:100::3"
       ]
     }
   }

   HTTP/1.1 200 OK
   Content-Length: 257
   Content-Type: application/alto-endpointcost+json

   {
     "meta": {
       "cost-type": {
         "cost-mode":   "numerical",
         "cost-metric": "delay-ow"
       }
     },
     "endpoint-cost-map": {
       "ipv6:2001:db8:100::1": {
         "ipv6:2001:db8:100::2": 10,
         "ipv6:2001:db8:100::3": 20
       }
     }
   }
```

4.1.4. Cost-Context Specification Considerations

   "nominal": Typically network one-way delay does not have a nominal
   value.

"sla": Many networks provide delay-related parameters in their
application-level SLAs. It is RECOMMENDED that the "parameters"
field of an "sla" one-way delay metric include a link (i.e., a field
named "link") providing an URI to the specification of SLA details,
if available. Such a specification can be either free text for
possible presentation to the user, or a formal specification. The
format of the specification is out of the scope of this document.

"estimation": The exact estimation method is out of the scope of this
document. There can be multiple sources to estimate one-way delay.
For example, the ALTO server may estimate the end-to-end delay by
aggregation of routing protocol link metrics; the server may also
estimate the delay using active, end-to-end measurements, for
example, using the IPPM framework [RFC2330].

If the estimation is computed by aggregation of routing protocol link
metrics (e.g., OSPF [RFC7471], IS-IS [RFC8570], or BGP-LS [RFC8571])
Unidirectional Delay link metrics, it is RECOMMENDED that the
"parameters" field of an "estimation" one-way delay metric include
the following information: (1) the RFC defining the routing protocol
metrics (e.g., https://www.rfc-editor.org/info/rfc7471 for RFC7471
derived metrics); (2) configurations of the routing link metrics such
as configured intervals; and (3) the aggregation method from link
metrics to end-to-end metrics. During aggregation from link metrics
to the end-to-end metric, the server should be cognizant of potential
issues when computing an end-to-end summary statistic from link
statistics. The default end-to-end average one-way delay is the sum
of average link one-way delays. If an ALTO server provides the min
and max statistical operators for the one-way delay metric, the
values can be computed directly from the routing link metrics, as
[RFC7471,RFC8570,RFC8571] provide Min/Max Unidirectional Link Delay.

If the estimation is from the IPPM measurement framework, it is
RECOMMEDED that the "parameters" field of an "estimation" one-way
delay metric includes the following information: the URI to the URI
field of the IPPM metric defined in the IPPM performance metric
[IANA-IPPM] registry (e.g., https://www.iana.org/assignments/
performance-metrics/OWDelay_Active_IP-UDP-Poisson-
Payload250B_RFC8912sec7_Seconds_95Percentile). The IPPM metric MUST
be one-way delay (i.e., IPPM OWDelay* metrics). The statistical
operator of the ALTO metric MUST be consistent with the IPPM
statistical property (e.g., 95-th percentile).

4.2. Cost Metric: Round-trip Delay (delay-rt)

4.2.1. Base Identifier

   The base identifier for this performance metric is "delay-rt".

4.2.2. Value Representation

   The metric value type is a single 'JSONNumber' type value conforming
   to the number specification of Section 6 of [RFC8259]. The number
   MUST be non-negative. The unit is expressed in microseconds.

4.2.3. Intended Semantics and Use

   Intended Semantics: To specify temporal and spatial aggregated round-
   trip delay between the specified source and specified destination.
   The base semantics is that it is the sum of one-way delay from the
   source to the destination and the one-way delay from the destination
   back to the source, where the one-way delay is defined in
   Section 4.1. A non-normative reference definition of end-to-end
   round-trip delay is [RFC2681]. The spatial aggregation level is
   specified in the query context (e.g., PID to PID, or endpoint to
   endpoint).

   Note that it is possible for a client to query two one-way delays
   (delay-ow) and then compute the round-trip delay. The server should
   be cognizant of the consistency of values.

   Use: This metric could be used either as a cost metric constraint
   attribute or as a returned cost metric in the response.

Example 2: Round-trip Delay of source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 238
Content-Type: application/alto-endpointcostparams+json
Accept:
  application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "delay-rt"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}
```

```
HTTP/1.1 200 OK
Content-Length: 245
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "delay-rt"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":    4,
      "ipv4:198.51.100.34": 3
    }
  }
}
```

4.2.4. Cost-Context Specification Considerations

"nominal": Typically network round-trip delay does not have a nominal
value.

"sla": See the "sla" entry in Section 4.1.4.

"estimation": See the "estimation" entry in Section 4.1.4. For
estimation by aggregation of routing protocol link metrics, the
aggregation should include all links from the source to the
destination and then back to the source; for estimation using IPPM,
the IPPM metric MUST be round-trip delay (i.e., IPPM RTDelay*
metrics). The statistical operator of the ALTO metric MUST be
consistent with the IPPM statistical property (e.g., 95-th
percentile).

4.3. Cost Metric: Delay Variation (delay-variation)

4.3.1. Base Identifier

The base identifier for this performance metric is "delay-variation".

4.3.2. Value Representation

The metric value type is a single 'JSONNumber' type value conforming
to the number specification of Section 6 of [RFC8259]. The number
MUST be non-negative. The unit is expressed in microseconds.

4.3.3. Intended Semantics and Use

Intended Semantics: To specify temporal and spatial aggregated delay
variation (also called delay jitter) with respect to the minimum
delay observed on the stream over the one-way delay from the
specified source and destination, where the one-way delay is defined
in Section 4.1. A non-normative reference definition of end-to-end
one-way delay variation is [RFC3393]. Note that [RFC3393] allows the
specification of a generic selection function F to unambiguously
define the two packets selected to compute delay variations. This
document defines the specific case that F selects as the "first"
packet the one with the smallest one-way delay. The spatial
aggregation level is specified in the query context (e.g., PID to
PID, or endpoint to endpoint).

Note that in statistics, variations are typically evaluated by the
distance from samples relative to the mean. In networking context,
it is more commonly defined from samples relative to the min. This
definition follows the networking convention.

Use: This metric could be used either as a cost metric constraint
attribute or as a returned cost metric in the response.

Example 3: Delay variation value on source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 245
Content-Type: application/alto-endpointcostparams+json
Accept:
   application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "delay-variation"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}

HTTP/1.1 200 OK
Content-Length: 252
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "delay-variation"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":    0,
      "ipv4:198.51.100.34": 1
    }
  }
}
```

4.3.4. Cost-Context Specification Considerations

"nominal": Typically network delay variation does not have a nominal
value.

"sla": See the "sla" entry in Section 4.1.4.

"estimation": See the "estimation" entry in Section 4.1.4. For
estimation by aggregation of routing protocol link metrics, the
default aggregation of the average of delay variations is the sum of
the link delay variations; for estimation using IPPM, the IPPM metric
MUST be delay variation (i.e., IPPM OWPDV* metrics). The statistical
operator of the ALTO metric MUST be consistent with the IPPM
statistical property (e.g., 95-th percentile).

4.4. Cost Metric: Loss Rate (lossrate)

4.4.1. Base Identifier

The base identifier for this performance metric is "lossrate".

4.4.2. Value Representation

The metric value type is a single 'JSONNumber' type value conforming
to the number specification of Section 6 of [RFC8259]. The number
MUST be non-negative. The value represents the percentage of packet
losses.

4.4.3. Intended Semantics and Use

Intended Semantics: To specify temporal and spatial aggregated one-
way packet loss rate from the specified source and the specified
destination. The base semantics of the metric is the Unidirectional
Link Loss metric defined in [RFC8571,RFC8570,RFC7471], but instead of
specifying the loss for a link, it is the aggregated loss of all
links from the source to the destination. The spatial aggregation
level is specified in the query context (e.g., PID to PID, or
endpoint to endpoint).

Use: This metric could be used as a cost metric constraint attribute
or as a returned cost metric in the response.

   Example 5: Loss rate value on source-destination endpoint pairs

   POST /endpointcost/lookup HTTP/1.1
   Host: alto.example.com
   Content-Length: 238
   Content-Type: application/alto-endpointcostparams+json
   Accept:
     application/alto-endpointcost+json,application/alto-error+json

   {
     "cost-type": {
       "cost-mode":   "numerical",
       "cost-metric": "lossrate"
     },
     "endpoints": {
       "srcs": [
         "ipv4:192.0.2.2"
       ],
       "dsts": [
         "ipv4:192.0.2.89",
         "ipv4:198.51.100.34"
       ]
     }
   }

   HTTP/1.1 200 OK
   Content-Length: 248
   Content-Type: application/alto-endpointcost+json

   {
     "meta": {
       "cost-type": {
         "cost-mode":   "numerical",
         "cost-metric": "lossrate"
       }
     },
     "endpoint-cost-map": {
       "ipv4:192.0.2.2": {
         "ipv4:192.0.2.89":   0,
         "ipv4:198.51.100.34": 0.01
       }
     }
   }

4.4.4. Cost-Context Specification Considerations

   "nominal": Typically packet loss rate does not have a nominal value,
   although some networks may specify zero losses.

"sla": See the "sla" entry in Section 4.1.4..

"estimation": See the "estimation" entry in Section 4.1.4. For
estimation by aggregation of routing protocol link metrics, the
default aggregation of the average of loss rate is the sum of the
link link loss rates. But this default aggregation is valid only if
two conditions are met: (1) it is valid only when link loss rates are
low, and (2) it assumes that each link's loss events are uncorrelated
with every other link's loss events. When loss rates at the links
are high but independent, the general formula for aggregating loss
assuming each link is independent is to compute end-to-end loss as
one minus the product of the success rate for each link. Aggregation
when losses at links are correlated can be more complex and the ALTO
server should be cognizant of correlated loss rates. For estimation
using IPPM, the IPPM metric MUST be packet loss (i.e., IPPM OWLoss*
metrics). The statistical operator of the ALTO metric MUST be
consistent with the IPPM statistical property (e.g., 95-th
percentile).

4.5. Cost Metric: Hop Count (hopcount)

The hopcount metric is mentioned in Section 9.2.3 of [RFC7285] as an
example. This section further clarifies its properties.

4.5.1. Base Identifier

The base identifier for this performance metric is "hopcount".

4.5.2. Value Representation

The metric value type is a single 'JSONNumber' type value conforming
to the number specification of Section 6 of [RFC8259]. The number
MUST be a non-negative integer (greater than or equal to 0). The
value represents the number of hops.

4.5.3. Intended Semantics and Use

Intended Semantics: To specify the number of hops in the path from
the specified source to the specified destination. The hop count is
a basic measurement of distance in a network and can be exposed as
the number of router hops computed from the routing protocols
originating this information. A hop, however, may represent other
units. The spatial aggregation level is specified in the query
context (e.g., PID to PID, or endpoint to endpoint).

Use: This metric could be used as a cost metric constraint attribute
or as a returned cost metric in the response.

Example 4: hopcount value on source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 238
Content-Type: application/alto-endpointcostparams+json
Accept:
  application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "hopcount"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}

HTTP/1.1 200 OK
Content-Length: 245
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "hopcount"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":    5,
      "ipv4:198.51.100.34": 3
    }
  }
}
```

4.5.4. Cost-Context Specification Considerations

"nominal": Typically hop count does not have a nominal value.

"sla": Typically hop count does not have an SLA value.

"estimation": The exact estimation method is out of the scope of this document. An example of estimating hopcounts is by importing from IGP routing protocols. It is RECOMMENDED that the "parameters" field of an "estimation" hop count define the meaning of a hop.

5. Throughput/Bandwidth Performance Metrics

This section introduces four throughput/bandwidth related metrics. Given a specified source to a specified destination, these metrics reflect the volume of traffic that the network can carry from the source to the destination.

5.1. Cost Metric: TCP Throughput (tput)

5.1.1. Base Identifier

The base identifier for this performance metric is "tput".

5.1.2. Value Representation

The metric value type is a single 'JSONNumber' type value conforming to the number specification of Section 6 of [RFC8259]. The number MUST be non-negative. The unit is bytes per second.

5.1.3. Intended Semantics and Use

Intended Semantics: To give the throughput of a TCP congestion-control conforming flow from the specified source to the specified destination. The throughput SHOULD be interpreted as only an estimation, and the estimation is designed only for bulk flows.

Use: This metric could be used as a cost metric constraint attribute or as a returned cost metric in the response.

Example 5: TCP throughput value on source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 234
Content-Type: application/alto-endpointcostparams+json
Accept:
  application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "tput"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}
```

```
HTTP/1.1 200 OK
Content-Length: 251
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "tput"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":    256000,
      "ipv4:198.51.100.34": 128000
    }
  }
}
```

5.1.4. Cost-Context Specification Considerations

"nominal": Typically TCP throughput does not have a nominal value,
and SHOULD NOT be generated.

"sla": Typically TCP throughput does not have an SLA value, and
SHOULD NOT be generated.

"estimation": The exact estimation method is out of the scope of this
document. It is RECOMMENDED that the "parameters" field of an
"estimation" TCP throughput metric include the following information:
(1) the congestion-control algorithm; and (2) the estimation
methodology. To specify (1), it is RECOMMENDED that the "parameters"
field (object) include a field named "congestion-control-algorithm",
which provides a URI for the specification of the algorithm; for
example, for an ALTO server to provide estimation to the throughput
of a Cubic Congestion control flow, its "parameters" includes a field
"congestion-control-algorithm", with value being set to
[I-D.ietf-tcpm-rfc8312bis]; for an ongoing congestion control
algorithm such as BBR, a a link to its specification. To specify
(2), the "parameters" includes as many details as possible; for
example, for TCP Cubic throughout estimation, the "parameters" field
specifies that the throughput is estimated by setting _C_ to 0.4, and
the Equation in Figure 8 of [I-D.ietf-tcpm-rfc8312bis] is applied; as
an alternative, the methodology may be based on the NUM model
[Prophet], or the G2 model [G2]. The exact specification of the
parameters field is out of the scope of this document.

5.2. Cost Metric: Residual Bandwidth (bw-residual)

5.2.1. Base Identifier

The base identifier for this performance metric is "bw-residual".

5.2.2. Value Representation

The metric value type is a single 'JSONNumber' type value that is
non-negative. The unit of measurement is bytes per second.

5.2.3. Intended Semantics and Use

Intended Semantics: To specify temporal and spatial residual
bandwidth from the specified source and the specified destination.
The base semantics of the metric is the Unidirectional Residual
Bandwidth metric defined in [RFC8571,RFC8570,RFC7471], but instead of
specifying the residual bandwidth for a link, it is the residual
bandwidth of the path from the source to the destination. Hence, it
is the minimal residual bandwidth among all links from the source to
the destination. When the max statistical operator is defined for
the metric, it typically provides the minimum of the link capacities
along the path, as the default value of the residual bandwidth of a
link is its link capacity [RFC8571,8570,7471]. The spatial
aggregation unit is specified in the query context (e.g., PID to PID,

or endpoint to endpoint).

The default statistical operator for residual bandwidth is the
current instantaneous sample; that is, the default is assumed to be
"cur".

Use: This metric could be used either as a cost metric constraint
attribute or as a returned cost metric in the response.

Example 7: bw-residual value on source-destination endpoint pairs

```
POST /endpointcost/lookup HTTP/1.1
Host: alto.example.com
Content-Length: 241
Content-Type: application/alto-endpointcostparams+json
Accept:
  application/alto-endpointcost+json,application/alto-error+json

{
  "cost-type": {
    "cost-mode":   "numerical",
    "cost-metric": "bw-residual"
  },
  "endpoints": {
    "srcs": [
      "ipv4:192.0.2.2"
    ],
    "dsts": [
      "ipv4:192.0.2.89",
      "ipv4:198.51.100.34"
    ]
  }
}
```

```
   HTTP/1.1 200 OK
   Content-Length: 255
   Content-Type: application/alto-endpointcost+json

   {
     "meta": {
       "cost-type": {
         "cost-mode":   "numerical",
         "cost-metric": "bw-residual"
       }
     },
     "endpoint-cost-map": {
       "ipv4:192.0.2.2":  {
         "ipv4:192.0.2.89":        0,
         "ipv4:198.51.100.34": 2000
       }
     }
   }
```

5.2.4. Cost-Context Specification Considerations

   "nominal": Typically residual bandwidth does not have a nominal
   value.

   "sla": Typically residual bandwidth does not have an "sla" value.

   "estimation": See the "estimation" entry in Section 4.1.4 on
   aggregation of routing protocol link metrics. The current ("cur")
   residual bandwidth of a path is the minimal of the residual bandwidth
   of all links on the path.

5.3. Cost Metric: Available Bandwidth (bw-available)

5.3.1. Base Identifier

   The base identifier for this performance metric is "bw-available".

5.3.2. Value Representation

   The metric value type is a single 'JSONNumber' type value that is
   non-negative. The unit of measurement is bytes per second.

5.3.3. Intended Semantics and Use

   Intended Semantics: To specify temporal and spatial available
   bandwidth from the specified source to the specified destination.
   The base semantics of the metric is the Unidirectional Available
   Bandwidth metric defined in [RFC8571,RFC8570,RFC7471], but instead of
   specifying the available bandwidth for a link, it is the available
   bandwidth of the path from the source to the destination. Hence, it
   is the minimal available bandwidth among all links from the source to
   the destination.The spatial aggregation unit is specified in the
   query context (e.g., PID to PID, or endpoint to endpoint).

   The default statistical operator for available bandwidth is the
   current instantaneous sample; that is, the default is assumed to be
   "cur".

   Use: This metric could be used either as a cost metric constraint
   attribute or as a returned cost metric in the response.

      Example 8: bw-available value on source-destination endpoint pairs

   POST /endpointcost/lookup HTTP/1.1
   Host: alto.example.com
   Content-Length: 244
   Content-Type: application/alto-endpointcostparams+json
   Accept:
     application/alto-endpointcost+json,application/alto-error+json

   {
     "cost-type": {
       "cost-mode":   "numerical",
       "cost-metric": "bw-available"
     },
     "endpoints": {
       "srcs": [
         "ipv4:192.0.2.2"
       ],
       "dsts": [
         "ipv4:192.0.2.89",
         "ipv4:198.51.100.34"
       ]
     }
   }

```
HTTP/1.1 200 OK
Content-Length: 255
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
      "cost-mode":   "numerical",
      "cost-metric": "bw-available"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.2": {
      "ipv4:192.0.2.89":        0,
      "ipv4:198.51.100.34": 2000
    }
  }
}
```

5.3.4. Cost-Context Specification Considerations

   "nominal": Typically available bandwidth does not have a nominal
   value.

   "sla": Typically available bandwidth does not have an "sla" value.

   "estimation": See the "estimation" entry in Section 4.1.4 on
   aggregation of routing protocol link metrics. The current ("cur")
   available bandwidth of a path is the minimum of the available
   bandwidth of all links on the path.

6. Operational Considerations

   The exact measurement infrastructure, measurement condition, and
   computation algorithms can vary from different networks, and are
   outside the scope of this document. Both the ALTO server and the
   ALTO clients, however, need to be cognizant of the operational issues
   discussed in the following sub-sections.

   Also, the performance metrics specified in this document are similar,
   in that they may use similar data sources and have similar issues in
   their calculation. Hence, this document specifies common issues
   unless one metric has its unique challenges.

6.1. Source Considerations

   The addition of the "cost-source" field is to solve a key issue: An
   ALTO server needs data sources to compute the cost metrics described
   in this document, and an ALTO client needs to know the data sources
   to better interpret the values.

   To avoid too fine-grained information, this document introduces
   "cost-source" to indicate only the high-level type of data sources:
   "estimation", "nominal" or "lsa", where "estimation" is a type of
   measurement data source, "nominal" is a type of static configuration,
   and "sla" is a type that is more based on policy.

   For estimation, for example, the ALTO server may use log servers or
   the OAM system as its data source as recommended by [RFC7971]. In
   particular, the cost metrics defined in this document can be computed
   using routing systems as the data sources.

6.2. Metric Timestamp Consideration

   Despite the introduction of the additional cost-context information,
   the metrics do not have a field to indicate the timestamps of the
   data used to compute the metrics. To indicate this attribute, the
   ALTO server SHOULD return HTTP "Last-Modified", to indicate the
   freshness of the data used to compute the performance metrics.

   If the ALTO client obtains updates through an incremental update
   mechanism [RFC8895], the client SHOULD assume that the metric is
   computed using a snapshot at the time that is approximated by the
   receiving time.

6.3. Backward Compatibility Considerations

   One potential issue introduced by the optional "cost-source" field is
   backward compatibility. Consider that an IRD which defines two cost-
   types with the same "cost-mode" and "cost-metric", but one with
   "cost-source" being "estimation" and the other being "sla". Then an
   ALTO client that is not aware of the extension will not be able to
   distinguish between these two types. A similar issue can arise even
   with a single cost-type, whose "cost-source" is "sla": an ALTO client
   that is not aware of this extension will ignore this field and
   consider the metric estimation.

   To address the backward-compatibility issue, if a "cost-metric" is
   "routingcost" and the metric contains a "cost-context" field, then it
   MUST be "estimation"; if it is not, the client SHOULD reject the
   information as invalid.

6.4. Computation Considerations

The metric values exposed by an ALTO server may result from
additional processing on measurements from data sources to compute
exposed metrics. This may involve data processing tasks such as
aggregating the results across multiple systems, removing outliers,
and creating additional statistics. There are two challenges on the
computation of ALTO performance metrics.

6.4.1. Configuration Parameters Considerations

Performance metrics often depend on configuration parameters, and
exposing such configuration parameters can help an ALTO client to
better understand the exposed metrics. In particular, an ALTO server
may be configured to compute a TE metric (e.g., packet loss rate) in
fixed intervals, say every T seconds. To expose this information,
the ALTO server may provide the client with two pieces of additional
information: (1) when the metrics are last computed, and (2) when the
metrics will be updated (i.e., the validity period of the exposed
metric values). The ALTO server can expose these two pieces of
information by using the HTTP response headers Last-Modified and
Expires.

6.4.2. Aggregation Computation Considerations

An ALTO server may not be able to measure the performance metrics to
be exposed. The basic issue is that the "source" information can
often be link level. For example, routing protocols often measure
and report only per link loss, not end-to-end loss; similarly,
routing protocols report link level available bandwidth, not end-to-
end available bandwidth. The ALTO server then needs to aggregate
these data to provide an abstract and unified view that can be more
useful to applications. The server should consider that different
metrics may use different aggregation computation. For example, the
end-to-end latency of a path is the sum of the latency of the links
on the path; the end-to-end available bandwidth of a path is the
minimum of the available bandwidth of the links on the path; in
contrast, aggregating loss values is complicated by the potential for
correlated loss events on different links in the path

7. Security Considerations

The properties defined in this document present no security
considerations beyond those in Section 15 of the base ALTO
specification [RFC7285].

However, concerns addressed in Sections 15.1, 15.2, and 15.3 of
[RFC7285] remain of utmost importance. Indeed, Traffic Engineering
(TE) performance is highly sensitive ISP information; therefore,
sharing TE metric values in numerical mode requires full mutual
confidence between the entities managing the ALTO server and the ALTO
client. ALTO servers will most likely distribute numerical TE
performance to ALTO clients under strict and formal mutual trust
agreements. On the other hand, ALTO clients must be cognizant on the
risks attached to such information that they would have acquired
outside formal conditions of mutual trust.

To mitigate confidentiality risks during information transport of TE
performance metrics, the operator should address the risk of ALTO
information being leaked to malicious Clients or third parties,
through attacks such as the person-in-the-middle (PITM) attacks. As
specified in "Protection Strategies" (Section 15.3.2 of [RFC7285]),
the ALTO Server should authenticate ALTO Clients when transmitting an
ALTO information resource containing sensitive TE performance
metrics. "Authentication and Encryption" (Section 8.3.5 of
[RFC7285]) specifies that "ALTO Server implementations as well as
ALTO Client implementations MUST support the "https" URI scheme of
[RFC7230] and Transport Layer Security (TLS) of [RFC8446]".

8. IANA Considerations

IANA has created and now maintains the "ALTO Cost Metric" registry,
listed in Section 14.2, Table 3 of [RFC7285]. This registry is
located at <https://www.iana.org/assignments/alto-protocol/alto-
protocol.xhtml#cost-metrics>. This document requests to add the
following entries to the "ALTO Cost Metric" registry.

```
+----------------+--------------------------+
| Identifier     | Intended Semantics       |
+----------------+--------------------------+
| delay-ow       | Section 4.1 of [RFCXXX]  |
| delay-rt       | Section 4.2 of [RFCXXX]  |
| delay-variation| Section 4.3 of [RFCXXX]  |
| lossrate       | Section 4.4 of [RFCXXX]  |
| hopcount       | Section 4.5 of [RFCXXX]  |
| tput           | Section 5.1 of [RFCXXX]  |
| bw-residual    | Section 5.2 of [RFCXXX]  |
| bw-available   | Section 5.3 of [RFCXXX]  |
+----------------+--------------------------+
```

   * [Note to the RFC Editor]: Please replace RFCXXX with the RFC
      number assigned to this document.

This document requests the creation of the "ALTO Cost Source"
registry. This registry serves two purposes. First, it ensures
uniqueness of identifiers referring to ALTO cost source types.
Second, it provides references to particular semantics of allocated
cost source types to be applied by both ALTO servers and applications
utilizing ALTO clients.

A new ALTO cost source can be added after IETF Review [RFC8126], to
ensure that proper documentation regarding the new ALTO cost source
and its security considerations have been provided. The RFC(s)
documenting the new cost source should be detailed enough to provide
guidance to both ALTO service providers and applications utilizing
ALTO clients as to how values of the registered ALTO cost source
should be interpreted. Updates and deletions of ALTO cost source
follow the same procedure.

Registered ALTO address type identifiers MUST conform to the
syntactical requirements specified in Section 3.1. Identifiers are
to be recorded and displayed as strings.

Requests to add a new value to the registry MUST include the
following information:

* Identifier: The name of the desired ALTO cost source type.

* Intended Semantics: ALTO cost source type carry with them
   semantics to guide their usage by ALTO clients. Hence, a document
   defining a new type should provide guidance to both ALTO service
   providers and applications utilizing ALTO clients as to how values
   of the registered ALTO endpoint property should be interpreted.

* Security Considerations: ALTO cost source types expose information
   to ALTO clients. ALTO service providers should be made aware of
   the security ramifications related to the exposure of a cost
   source type.

This specification requests registration of the identifiers
"nominal", "sla", and "estimation" listed in the table below.
Semantics for the these are documented in Section 3.1, and security
considerations are documented in Section 7.

```
+-----------+------------------------------+---------------+
| Identifier | Intended Semantics          | Security      |
|           |                              | Considerations |
+-----------+------------------------------+---------------+
| nominal   | Values in nominal cases;     | Section 7 of  |
|           |    Section 3.1 of [RFCXXX]   |    [RFCXXX]   |
| sla       | Values reflecting service level | Section 7 of |
|           | agreement; Section 3.1 of    |    [RFCXXX]   |
|           |    [RFCXXXX]                 |               |
| estimation | Values by estimation;       | Section 7 of  |
|           |    Section 3.1 of [RFCXXX]   |    [RFCXXX]   |
+-----------+------------------------------+---------------+
```

9. Acknowledgments

10. References

10.1. Normative References

[I-D.ietf-tcpm-rfc8312bis]
           Xu, L., Ha, S., Rhee, I., Goel, V., and L. Eggert, "CUBIC
           for Fast and Long-Distance Networks", Work in Progress,
           Internet-Draft, draft-ietf-tcpm-rfc8312bis-07, 4 March
           2022, <https://www.ietf.org/archive/id/draft-ietf-tcpm-
           rfc8312bis-07.txt>.

[IANA-IPPM]
           IANA, "Performance Metrics Registry,
           https://www.iana.org/assignments/performance-metrics/
           performance-metrics.xhtml".

[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>.

   [RFC3630] Katz, D., Kompella, K., and D. Yeung, "Traffic Engineering
              (TE) Extensions to OSPF Version 2", RFC 3630,
              DOI 10.17487/RFC3630, September 2003,
              <https://www.rfc-editor.org/info/rfc3630>.

   [RFC5305] Li, T. and H. Smit, "IS-IS Extensions for Traffic
              Engineering", RFC 5305, DOI 10.17487/RFC5305, October
              2008, <https://www.rfc-editor.org/info/rfc5305>.

   [RFC6390] Clark, A. and B. Claise, "Guidelines for Considering New
              Performance Metric Development", BCP 170, RFC 6390,
              DOI 10.17487/RFC6390, October 2011,
              <https://www.rfc-editor.org/info/rfc6390>.

   [RFC7230] Fielding, R., Ed. and J. Reschke, Ed., "Hypertext Transfer
              Protocol (HTTP/1.1): Message Syntax and Routing",
              RFC 7230, DOI 10.17487/RFC7230, June 2014,
              <https://www.rfc-editor.org/info/rfc7230>.

   [RFC7285] Alimi, R., Ed., Penno, R., Ed., Yang, Y., Ed., Kiesel, S.,
              Previdi, S., Roome, W., Shalunov, S., and R. Woundy,
              "Application-Layer Traffic Optimization (ALTO) Protocol",
              RFC 7285, DOI 10.17487/RFC7285, September 2014,
              <https://www.rfc-editor.org/info/rfc7285>.

   [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>.

   [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>.

   [RFC8259] Bray, T., Ed., "The JavaScript Object Notation (JSON) Data
              Interchange Format", STD 90, RFC 8259,
              DOI 10.17487/RFC8259, December 2017,
              <https://www.rfc-editor.org/info/rfc8259>.

   [RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol
              Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018,
              <https://www.rfc-editor.org/info/rfc8446>.

   [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>.

   [RFC8895] Roome, W. and Y. Yang, "Application-Layer Traffic
              Optimization (ALTO) Incremental Updates Using Server-Sent
              Events (SSE)", RFC 8895, DOI 10.17487/RFC8895, November
              2020, <https://www.rfc-editor.org/info/rfc8895>.

10.2. Informative References

   [FlowDirector]
              Pujol, E., Poese, I., Zerwas, J., Smaragdakis, G., and A.
              Feldmann, "Steering Hyper-Giants' Traffic at Scale", ACM
              CoNEXT 2020, 2020.

   [G2]   Ros-Giralt, J., Bohara, A., Yellamraju, S., and et. al.,
              "On the Bottleneck Structure of Congestion-Controlled
              Networks", ACM SIGMETRICS 2019, 2020.

   [I-D.corre-quic-throughput-testing]
              Corre, K., "Framework for QUIC Throughput Testing", Work
              in Progress, Internet-Draft, draft-corre-quic-throughput-
              testing-00, 17 September 2021,
              <https://www.ietf.org/archive/id/draft-corre-quic-
              throughput-testing-00.txt>.

   [Prometheus]
              Volz, J. and B. Rabenstein, "Prometheus: A Next-Generation
              Monitoring System", 2015.

   [Prophet] Gao, K., Zhang, J., and YR. Yang, "Prophet: Fast, Accurate
              Throughput Prediction with Reactive Flows", ACM/IEEE
              Transactions on Networking July, 2020.

   [RFC2330] Paxson, V., Almes, G., Mahdavi, J., and M. Mathis,
              "Framework for IP Performance Metrics", RFC 2330,
              DOI 10.17487/RFC2330, May 1998,
              <https://www.rfc-editor.org/info/rfc2330>.

   [RFC2681] Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip
              Delay Metric for IPPM", RFC 2681, DOI 10.17487/RFC2681,
              September 1999, <https://www.rfc-editor.org/info/rfc2681>.

   [RFC3393] Demichelis, C. and P. Chimento, "IP Packet Delay Variation
              Metric for IP Performance Metrics (IPPM)", RFC 3393,
              DOI 10.17487/RFC3393, November 2002,
              <https://www.rfc-editor.org/info/rfc3393>.

   [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>.

   [RFC7679] Almes, G., Kalidindi, S., Zekauskas, M., and A. Morton,
              Ed., "A One-Way Delay Metric for IP Performance Metrics
              (IPPM)", STD 81, RFC 7679, DOI 10.17487/RFC7679, January
              2016, <https://www.rfc-editor.org/info/rfc7679>.

   [RFC7971] Stiemerling, M., Kiesel, S., Scharf, M., Seidel, H., and
              S. Previdi, "Application-Layer Traffic Optimization (ALTO)
              Deployment Considerations", RFC 7971,
              DOI 10.17487/RFC7971, October 2016,
              <https://www.rfc-editor.org/info/rfc7971>.

   [RFC9000] Iyengar, J., Ed. and M. Thomson, Ed., "QUIC: A UDP-Based
              Multiplexed and Secure Transport", RFC 9000,
              DOI 10.17487/RFC9000, May 2021,
              <https://www.rfc-editor.org/info/rfc9000>.

Authors' Addresses

   Qin Wu
   Huawei
   101 Software Avenue, Yuhua District
   Nanjing
   Jiangsu, 210012
   China
   Email: bill.wu@huawei.com

   Y. Richard Yang
   Yale University
   51 Prospect St
   New Haven, CT 06520
   United States of America
   Email: yry@cs.yale.edu

Young Lee
Samsung
Email: young.lee@gmail.com

Dhruv Dhody
Huawei
Leela Palace
Bangalore 560008
Karnataka
India
Email: dhruv.ietf@gmail.com

Sabine Randriamasy
Nokia Bell Labs
Route de Villejust
91460 Nozay
France
Email: sabine.randriamasy@nokia-bell-labs.com

Luis Miguel Contreras Murillo
Telefonica
Madrid
Spain
Email: luismiguel.contrerasmurillo@telefonica.com