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                  Initial Performance Metrics Registry Entries

Abstract

   This memo defines the set of initial entries for the IANA Registry of
   Performance Metrics. The set includes UDP Round-Trip Latency and
   Loss, Packet Delay Variation, DNS Response Latency and Loss, UDP
   Poisson One-Way Delay and Loss, UDP Periodic One-Way Delay and Loss,
   ICMP Round-Trip Latency and Loss, and TCP Round-Trip Delay and Loss.

Status of This Memo

   This is an Internet Standards Track document.

   This document is a product of the Internet Engineering Task Force
   (IETF). It represents the consensus of the IETF community. It has
   received public review and has been approved for publication by the
   Internet Engineering Steering Group (IESG). Further information on
   Internet Standards is available in Section 2 of RFC 7841.

   Information about the current status of this document, any errata,
   and how to provide feedback on it may be obtained at
   https://www.rfc-editor.org/info/rfc8912.

Table of Contents

1. Introduction

   This memo defines an initial set of entries for the Performance
   Metrics Registry. It uses terms and definitions from the IP
   Performance Metrics (IPPM) literature, primarily [RFC2330].

   Although there are several standard templates for organizing
   specifications of Performance Metrics (see [RFC7679] for an example
   of the traditional IPPM template, based to a large extent on the
   Benchmarking Methodology Working Group's traditional template in
   [RFC1242], and see [RFC6390] for a similar template), none of these
   templates were intended to become the basis for the columns of an
   IETF-wide Registry of metrics. While examining aspects of metric
   specifications that need to be registered, it became clear that none
   of the existing metric templates fully satisfy the particular needs
   of a Registry.

   Therefore, [RFC8911] defines the overall format for a Performance
   Metrics Registry. Section 5 of [RFC8911] also gives guidelines for
   those requesting registration of a Metric -- that is, the creation of
   one or more entries in the Performance Metrics Registry:

   | In essence, there needs to be evidence that (1) a candidate
   | Registered Performance Metric has significant industry interest or
   | has seen deployment and (2) there is agreement that the candidate
   | Registered Performance Metric serves its intended purpose.

   The process defined in [RFC8911] also requires that new entries be
   administered by IANA through the Specification Required policy
   [RFC8126], which will ensure that the metrics are tightly defined.

1.1. Requirements Language

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

[2](#). Scope

   This document defines a set of initial Performance Metrics Registry
   Entries. Most are Active Performance Metrics, which are based on
   RFCs prepared in the IPPM Working Group of the IETF, according to
   their framework [[RFC2330](#)] and its updates.

[3](#). Registry Categories and Columns

   This memo uses the terminology defined in [[RFC8911](#)].

   This section provides the categories and columns of the Registry, for
   easy reference. An entry (row) therefore gives a complete
   description of a Registered Metric.

   Registry Categories and Columns are shown below in this format:

```
    Category
    ------------------...
    Column |  Column |...
```

   Summary

```
----------------------------------------------------------------
Identifier | Name | URI | Desc. | Reference | Change      | Ver |
           |      |     |       |           | Controller |
```

   Metric Definition

```
--------------------------------------------
Reference Definition | Fixed Parameters |
```

   Method of Measurement

```
-------------------------------------------------------------------------
Reference | Packet    | Traffic | Sampling     | Runtime    | Role |
Method    | Stream    | Filter  | Distribution | Parameters |      |
          | Generation |
```

   Output

```
--------------------------------------------
Type | Reference  | Units | Calibration |
     | Definition |       |             |
```

   Administrative Information

```
----------------------------------------
Status |Requester | Rev | Rev. Date |
```

   Comments and Remarks

```
--------------------
```

[4](#). UDP Round-Trip Latency and Loss Registry Entries

   This section specifies an initial Registry Entry for UDP Round-Trip

Latency and another entry for the UDP Round-Trip Loss Ratio.

   Note: Each Registry Entry only produces a "raw" output or a
   statistical summary. To describe both "raw" and one or more
   statistics efficiently, the Identifier, Name, and Output
   categories can be split, and a single section can specify two or
   more closely related metrics. For example, this section specifies
   two Registry Entries with many common columns. See [Section 7](#) for
   an example specifying multiple Registry Entries with many common
   columns.

All column entries besides the ID, Name, Description, and Output
Reference Method categories are the same; thus, this section defines
two closely related Registry Entries. As a result, IANA has also
assigned a corresponding URL to each of the two Named Metrics.

4.1. Summary

This category includes multiple indexes to the Registry Entries: the
element ID and Metric Name.

4.1.1. ID (Identifier)

IANA has allocated the numeric Identifiers 1 and 2 for the two Named
Metric Entries in [Section 4](#). See [Section 4.1.2](#) for mapping to Names.

4.1.2. Name

1: RTDelay_Active_IP-UDP-Periodic_RFC8912sec4_Seconds_95Percentile

2: RTLoss_Active_IP-UDP-Periodic_RFC8912sec4_Percent_LossRatio

4.1.3. URI

URL: [https://www.iana.org/assignments/performance-metrics/
RTDelay_Active_IP-UDP-Periodic_RFC8912sec4_Seconds_95Percentile](https://www.iana.org/assignments/performance-metrics/RTDelay_Active_IP-UDP-Periodic_RFC8912sec4_Seconds_95Percentile)

URL: [https://www.iana.org/assignments/performance-metrics/
RTLoss_Active_IP-UDP-Periodic_RFC8912sec4_Percent_LossRatio](https://www.iana.org/assignments/performance-metrics/RTLoss_Active_IP-UDP-Periodic_RFC8912sec4_Percent_LossRatio)

4.1.4. Description

RTDelay: This metric assesses the delay of a stream of packets
   exchanged between two hosts (which are the two measurement
   points). The output is the round-trip delay for all successfully
   exchanged packets expressed as the 95th percentile of their
   conditional delay distribution.

RTLoss: This metric assesses the loss ratio of a stream of packets
   exchanged between two hosts (which are the two measurement
   points). The output is the round-trip loss ratio for all

transmitted packets expressed as a percentage.

4.1.5. Change Controller

   IETF

4.1.6. Version (of Registry Format)

   1.0

4.2. Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

4.2.1. Reference Definition

   For delay:

      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>. [RFC2681]

      Section 2.4 of [RFC2681] provides the reference definition of the
      singleton (single value) round-trip delay metric. Section 3.4 of
      [RFC2681] provides the reference definition expanded to cover a
      multi-singleton sample. Note that terms such as "singleton" and
      "sample" are defined in Section 11 of [RFC2330].

      Note that although the definition of round-trip delay between the
      Source (Src) and the Destination (Dst) as provided in Section 2.4
      of [RFC2681] is directionally ambiguous in the text, this metric
      tightens the definition further to recognize that the host in the
      Src Role will send the first packet to the host in the Dst Role
      and will ultimately receive the corresponding return packet from
      the Dst (when neither is lost).

      Finally, note that the variable "dT" is used in [RFC2681] to refer
      to the value of round-trip delay in metric definitions and
      methods. The variable "dT" has been reused in other IPPM
      literature to refer to different quantities and cannot be used as
      a global variable name.

   For loss:

      Morton, A., "Round-Trip Packet Loss Metrics", RFC 6673, DOI
      10.17487/RFC6673, August 2012, <https://www.rfc-editor.org/info/
      rfc6673>. [RFC6673]

   Both Delay and Loss metrics employ a maximum waiting time for

received packets, so the count of lost packets to total packets sent
is the basis for the loss ratio calculation as per Section 6.1 of
[RFC6673].

4.2.2. Fixed Parameters

   Type-P as defined in Section 13 of [RFC2330]:
      IPv4 header values:
         DSCP: Set to 0
         TTL: Set to 255
         Protocol: Set to 17 (UDP)

      IPv6 header values:
         DSCP: Set to 0
         Hop Count: Set to 255
         Next Header: Set to 17 (UDP)
         Flow Label: Set to 0
         Extension Headers: None

      UDP header values:
         Checksum: The checksum MUST be calculated and the non-zero
            checksum included in the header

      UDP Payload:
         Total of 100 bytes

   Other measurement Parameters:
      Tmax: A loss threshold waiting time with value 3.0, expressed in
         units of seconds, as a positive value of type decimal64 with
         fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a
         resolution of 0.0001 seconds (0.1 ms), with lossless conversion
         to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

4.3. Method of Measurement

   This category includes columns for references to relevant sections of
   the RFC(s) and any supplemental information needed to ensure an
   unambiguous method for implementations.

4.3.1. Reference Methods

   The methodology for this metric (equivalent to Type-P-Round-trip-
   Delay and Type-P-Round-trip-Delay-Poisson-Stream) is defined as in
   Section 2.6 of [RFC2681] (for singletons) and Section 3.6 of
   [RFC2681] (for samples) using the Type-P and Tmax defined in the
   Fixed Parameters column. However, the Periodic stream will be
   generated according to [RFC3432].

   The reference method distinguishes between long-delayed packets and
   lost packets by implementing a maximum waiting time for packet
   arrival. Tmax is the waiting time used as the threshold to declare a

packet lost. Lost packets SHALL be designated as having undefined
delay and counted for the RTLoss metric [RFC6673].

The calculations on the delay (RTT) SHALL be performed on the
conditional distribution, conditioned on successful packet arrival
within Tmax. Also, when all packet delays are stored, the process
that calculates the RTT value MUST enforce the Tmax threshold on
stored values before calculations. See Section 4.1 of [RFC3393] for
details on the conditional distribution to exclude undefined values
of delay, and see Section 5 of [RFC6703] for background on this
analysis choice.

The reference method requires some way to distinguish between
different packets in a stream to establish correspondence between
sending times and receiving times for each successfully arriving
packet. Sequence numbers or other send-order identification MUST be
retained at the Src or included with each packet to disambiguate
packet reordering if it occurs.

If a standard measurement protocol is employed, then the measurement
process will determine the sequence numbers or timestamps applied to
test packets after the Fixed and Runtime Parameters are passed to
that process. The chosen measurement protocol will dictate the
format of sequence numbers and timestamps, if they are conveyed in
the packet payload.

Refer to Section 4.4 of [RFC6673] for an expanded discussion of the
instruction to "send a Type-P packet back to the Src as quickly as
possible" in Section 2.6 of [RFC2681]. Section 8 of [RFC6673]
presents additional requirements that MUST be included in the Method
of Measurement for this metric.

4.3.2. Packet Stream Generation

This section provides details regarding packet traffic, which is used
as the basis for measurement. In IPPM Metrics, this is called the
"stream"; this stream can easily be described by providing the list
of stream Parameters.

Section 3 of [RFC3432] prescribes the method for generating Periodic
streams using associated Parameters.

incT: The nominal duration of the inter-packet interval, first bit
   to first bit, with value 0.0200, expressed in units of seconds, as
   a positive value of type decimal64 with fraction digits = 4 (see
   Section 9.3 of [RFC6020]) and with a resolution of 0.0001 seconds
   (0.1 ms).

dT: The duration of the interval for allowed sample start times,
   with value 1.0, expressed in units of seconds, as a positive value
   of type decimal64 with fraction digits = 4 (see Section 9.3 of

[RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms).

   Note: An initiation process with a number of control exchanges
   resulting in unpredictable start times (within a time interval)
   may be sufficient to avoid synchronization of periodic streams and
   is a valid replacement for selecting a start time at random from a
   fixed interval.

The T0 Parameter will be reported as a measured Parameter.
Parameters incT and dT are Fixed Parameters.

4.3.3. Traffic Filtering (Observation) Details

N/A

4.3.4. Sampling Distribution

N/A

4.3.5. Runtime Parameters and Data Format

Runtime Parameters are input factors that must be determined,
configured into the measurement system, and reported with the results
for the context to be complete.

Src: The IP address of the host in the Src Role (format
   ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
   for IPv6; see Section 4 of [RFC6991]).

Dst: The IP address of the host in the Dst Role (format
   ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
   for IPv6; see Section 4 of [RFC6991]).

T0: A time, the start of a measurement interval (format "date-time"
   as specified in Section 5.6 of [RFC3339]; see also "date-and-time"
   in Section 3 of [RFC6991]). The UTC Time Zone is required by
   Section 6.1 of [RFC2330]. When T0 is "all-zeros", a start time is
   unspecified and Tf is to be interpreted as the duration of the
   measurement interval. The start time is controlled through other
   means.

Tf: A time, the end of a measurement interval (format "date-time" as
   specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
   Section 3 of [RFC6991]). The UTC Time Zone is required by
   Section 6.1 of [RFC2330]. When T0 is "all-zeros", an ending time
   and date is ignored and Tf is interpreted as the duration of the
   measurement interval.

4.3.6. Roles

Src: Launches each packet and waits for return transmissions from

the Dst.

   Dst: Waits for each packet from the Src and sends a return packet to
      the Src.

4.4. Output

   This category specifies all details of the output of measurements
   using the metric.

4.4.1. Type

   Percentile: For the conditional distribution of all packets with a
   valid value of round-trip delay (undefined delays are excluded), this
   is a single value corresponding to the 95th percentile, as follows:

   See Section 4.1 of [RFC3393] for details on the conditional
   distribution to exclude undefined values of delay, and see Section 5
   of [RFC6703] for background on this analysis choice.

   The percentile = 95, meaning that the reported delay, "95Percentile",
   is the smallest value of round-trip delay for which the Empirical
   Distribution Function, EDF(95Percentile), is greater than or equal to
   95% of the singleton round-trip delay values in the conditional
   distribution. See Section 11.3 of [RFC2330] for the definition of
   the percentile statistic using the EDF.

   For LossRatio, the count of lost packets to total packets sent is the
   basis for the loss ratio calculation as per Section 6.1 of [RFC6673].

4.4.2. Reference Definition

   For all outputs:

   T0: The start of a measurement interval (format "date-time" as
      specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
      Section 3 of [RFC6991]). The UTC Time Zone is required by
      Section 6.1 of [RFC2330].

   Tf: The end of a measurement interval (format "date-time" as
      specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
      Section 3 of [RFC6991]). The UTC Time Zone is required by
      Section 6.1 of [RFC2330].

   TotalPkts: The count of packets sent by the Src to the Dst during
      the measurement interval.

   95Percentile: The time value of the result is expressed in units of
      seconds, as a positive value of type decimal64 with fraction
      digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns).

Percent_LossRatio: The numeric value of the result is expressed in
      units of lost packets to total packets times 100%, as a positive
      value of type decimal64 with fraction digits = 9 (see Section 9.3
      of [RFC6020]) with a resolution of 0.0000000001.

4.4.3. Metric Units

   The 95th percentile of round-trip delay is expressed in seconds.

   The round-trip loss ratio is expressed as a percentage of lost
   packets to total packets sent.

4.4.4. Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the
   systematic and random errors of a time measurement. Calibration in-
   situ could be enabled with an internal loopback at the Source host
   that includes as much of the measurement system as possible, performs
   address manipulation as needed, and provides some form of isolation
   (e.g., deterministic delay) to avoid send-receive interface
   contention. Some portion of the random and systematic error can be
   characterized in this way.

   When a measurement controller requests a calibration measurement, the
   loopback is applied and the result is output in the same format as a
   normal measurement, with an additional indication that it is a
   calibration result.

   Both internal loopback calibration and clock synchronization can be
   used to estimate the available accuracy of the Output Metric Units.
   For example, repeated loopback delay measurements will reveal the
   portion of the output result resolution that is the result of system
   noise and is thus inaccurate.

4.5. Administrative Items

4.5.1. Status

   Current

4.5.2. Requester

   RFC 8912

4.5.3. Revision

   1.0

4.5.4. Revision Date

2021-11-17

4.6. Comments and Remarks

None

5. Packet Delay Variation Registry Entry

This section gives an initial Registry Entry for a Packet Delay
Variation (PDV) metric.

5.1. Summary

This category includes multiple indexes to the Registry Entry: the
element ID and Metric Name.

5.1.1. ID (Identifier)

IANA has allocated the numeric Identifier 3 for the Named Metric
Entry in Section 5. See Section 5.1.2 for mapping to Name.

5.1.2. Name

3: OWPDV_Active_IP-UDP-Periodic_RFC8912sec5_Seconds_95Percentile

5.1.3. URI

URL: https://www.iana.org/assignments/performance-metrics/
OWPDV_Active_IP-UDP-Periodic_RFC8912sec5_Seconds_95Percentile

5.1.4. Description

This metric assesses packet delay variation with respect to the
minimum delay observed on the periodic stream. The output is
expressed as the 95th percentile of the one-way packet delay
variation distribution.

5.1.5. Change Controller

IETF

5.1.6. Version (of Registry Format)

1.0

5.2. Metric Definition

This category includes columns to prompt the entry of all necessary
details related to the metric definition, including the RFC reference
and values of input factors, called "Fixed Parameters".

5.2.1. Reference Definition

   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>. [RFC2330]

   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>. [RFC3393]

   Morton, A. and B. Claise, "Packet Delay Variation Applicability
   Statement", RFC 5481, DOI 10.17487/RFC5481, March 2009,
   <https://www.rfc-editor.org/info/rfc5481>. [RFC5481]

   Mills, D., Martin, J., Ed., Burbank, J., and W. Kasch, "Network Time
   Protocol Version 4: Protocol and Algorithms Specification", RFC 5905,
   DOI 10.17487/RFC5905, June 2010, <https://www.rfc-editor.org/info/
   rfc5905>. [RFC5905]

   See Sections 2.4 and 3.4 of [RFC3393]. The measured singleton delay
   differences are referred to by the variable name "ddT" (applicable to
   all forms of delay variation). However, this Metric Entry specifies
   the PDV form defined in Section 4.2 of [RFC5481], where the singleton
   PDV for packet i is referred to by the variable name "PDV(i)".

5.2.2. Fixed Parameters

   IPv4 header values:
      DSCP: Set to 0
      TTL: Set to 255
      Protocol: Set to 17 (UDP)

   IPv6 header values:
      DSCP: Set to 0
      Hop Count: Set to 255
      Next Header: Set to 17 (UDP)
      Flow Label: Set to 0
      Extension Headers: None

   UDP header values:
      Checksum: The checksum MUST be calculated and the non-zero
         checksum included in the header

   UDP Payload:
      Total of 200 bytes

   Other measurement Parameters:
      Tmax: A loss threshold waiting time with value 3.0, expressed in
         units of seconds, as a positive value of type decimal64 with
         fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a
         resolution of 0.0001 seconds (0.1 ms), with lossless conversion

to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

   F: A selection function unambiguously defining the packets from
the stream selected for the metric. See Section 4.2 of
[RFC5481] for the PDV form.

See the Packet Stream Generation section for two additional Fixed
Parameters.

5.3. Method of Measurement

This category includes columns for references to relevant sections of
the RFC(s) and any supplemental information needed to ensure an
unambiguous method for implementations.

5.3.1. Reference Methods

See Sections 2.6 and 3.6 of [RFC3393] for general singleton element
calculations. This Metric Entry requires implementation of the PDV
form defined in Section 4.2 of [RFC5481]. Also see measurement
considerations in Section 8 of [RFC5481].

The reference method distinguishes between long-delayed packets and
lost packets by implementing a maximum waiting time for packet
arrival. Tmax is the waiting time used as the threshold to declare a
packet lost. Lost packets SHALL be designated as having undefined
delay.

The calculations on the one-way delay SHALL be performed on the
conditional distribution, conditioned on successful packet arrival
within Tmax. Also, when all packet delays are stored, the process
that calculates the one-way delay value MUST enforce the Tmax
threshold on stored values before calculations. See Section 4.1 of
[RFC3393] for details on the conditional distribution to exclude
undefined values of delay, and see Section 5 of [RFC6703] for
background on this analysis choice.

The reference method requires some way to distinguish between
different packets in a stream to establish correspondence between
sending times and receiving times for each successfully arriving
packet. Sequence numbers or other send-order identification MUST be
retained at the Src or included with each packet to disambiguate
packet reordering if it occurs.

If a standard measurement protocol is employed, then the measurement
process will determine the sequence numbers or timestamps applied to
test packets after the Fixed and Runtime Parameters are passed to
that process. The chosen measurement protocol will dictate the
format of sequence numbers and timestamps, if they are conveyed in
the packet payload.

5.3.2. Packet Stream Generation

This section provides details regarding packet traffic, which is used as the basis for measurement. In IPPM Metrics, this is called the "stream"; this stream can easily be described by providing the list of stream Parameters.

Section 3 of [RFC3432] prescribes the method for generating Periodic streams using associated Parameters.

incT: The nominal duration of the inter-packet interval, first bit to first bit, with value 0.0200, expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms).

dT: The duration of the interval for allowed sample start times, with value 1.0, expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms).

Note: An initiation process with a number of control exchanges resulting in unpredictable start times (within a time interval) may be sufficient to avoid synchronization of periodic streams and is a valid replacement for selecting a start time at random from a fixed interval.

The T0 Parameter will be reported as a measured Parameter. Parameters incT and dT are Fixed Parameters.

5.3.3. Traffic Filtering (Observation) Details

N/A

5.3.4. Sampling Distribution

N/A

5.3.5. Runtime Parameters and Data Format

Src: The IP address of the host in the Src Role (format ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value for IPv6; see Section 4 of [RFC6991]).

Dst: The IP address of the host in the Dst Role (format ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value for IPv6; see Section 4 of [RFC6991]).

T0: A time, the start of a measurement interval (format "date-time" as specified in Section 5.6 of [RFC3339]; see also "date-and-time" in Section 3 of [RFC6991]). The UTC Time Zone is required by

Section 6.1 of [RFC2330]. When T0 is "all-zeros", a start time is
unspecified and Tf is to be interpreted as the duration of the
measurement interval. The start time is controlled through other
means.

Tf: A time, the end of a measurement interval (format "date-time" as
     specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
     Section 3 of [RFC6991]). The UTC Time Zone is required by
     Section 6.1 of [RFC2330]. When T0 is "all-zeros", an ending time
     and date is ignored and Tf is interpreted as the duration of the
     measurement interval.

5.3.6. Roles

Src: Launches each packet and waits for return transmissions from
      the Dst.

Dst: Waits for each packet from the Src and sends a return packet to
      the Src (when required by the test protocol).

5.4. Output

This category specifies all details of the output of measurements
using the metric.

5.4.1. Type

Percentile: For the conditional distribution of all packets with a
valid value of one-way delay (undefined delays are excluded), this is
a single value corresponding to the 95th percentile, as follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

The percentile = 95, meaning that the reported delay, "95Percentile",
is the smallest value of one-way PDV for which the Empirical
Distribution Function, EDF(95Percentile), is greater than or equal to
95% of the singleton one-way PDV values in the conditional
distribution. See Section 11.3 of [RFC2330] for the definition of
the percentile statistic using the EDF.

5.4.2. Reference Definition

T0: The start of a measurement interval (format "date-time" as
     specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
     Section 3 of [RFC6991]). The UTC Time Zone is required by
     Section 6.1 of [RFC2330].

Tf: The end of a measurement interval (format "date-time" as
     specified in Section 5.6 of [RFC3339]; see also "date-and-time" in

Section 3 of [RFC6991]). The UTC Time Zone is required by
   Section 6.1 of [RFC2330].

   95Percentile: The time value of the result is expressed in units of
      seconds, as a positive value of type decimal64 with fraction
      digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per Section 6 of [RFC5905].

5.4.3. Metric Units

   The 95th percentile of one-way PDV is expressed in seconds.

5.4.4. Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the
   systematic and random errors of a time measurement. Calibration in-
   situ could be enabled with an internal loopback that includes as much
   of the measurement system as possible, performs address manipulation
   as needed, and provides some form of isolation (e.g., deterministic
   delay) to avoid send-receive interface contention. Some portion of
   the random and systematic error can be characterized in this way.

   For one-way delay measurements, the error calibration must include an
   assessment of the internal clock synchronization with its external
   reference (this internal clock is supplying timestamps for
   measurement). In practice, the time offsets [RFC5905] of clocks at
   both the Source and Destination are needed to estimate the systematic
   error due to imperfect clock synchronization (the time offsets are
   smoothed; thus, the random variation is not usually represented in
   the results).

   time_offset: The time value of the result is expressed in units of
      seconds, as a signed value of type decimal64 with fraction
      digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per Section 6 of [RFC5905].

   When a measurement controller requests a calibration measurement, the
   loopback is applied and the result is output in the same format as a
   normal measurement, with an additional indication that it is a
   calibration result. In any measurement, the measurement function
   SHOULD report its current estimate of the time offset [RFC5905] as an
   indicator of the degree of synchronization.

   Both internal loopback calibration and clock synchronization can be
   used to estimate the available accuracy of the Output Metric Units.
   For example, repeated loopback delay measurements will reveal the
   portion of the output result resolution that is the result of system
   noise and is thus inaccurate.

5.5. Administrative Items

5.5.1. Status

   Current

5.5.2. Requester

   RFC 8912

5.5.3. Revision

   1.0

5.5.4. Revision Date

   2021-11-17

5.6. Comments and Remarks

   Lost packets represent a challenge for delay variation metrics. See
   Section 4.1 of [RFC3393] and the delay variation applicability
   statement [RFC5481] for extensive analysis and comparison of PDV and
   an alternate metric, IPDV (Inter-Packet Delay Variation).

6. DNS Response Latency and Loss Registry Entries

   This section gives initial Registry Entries for DNS Response Latency
   and Loss from a network user's perspective, for a specific named
   resource. The metric can be measured repeatedly for different named
   resources. [RFC2681] defines a round-trip delay metric. We build on
   that metric by specifying several of the input Parameters to
   precisely define two metrics for measuring DNS latency and loss.

   All column entries besides the ID, Name, Description, and Output
   Reference Method categories are the same; thus, this section defines
   two closely related Registry Entries. As a result, IANA has assigned
   corresponding URLs to each of the two Named Metrics.

6.1. Summary

   This category includes multiple indexes to the Registry Entries: the
   element ID and Metric Name.

6.1.1. ID (Identifier)

   IANA has allocated the numeric Identifiers 4 and 5 for the two Named
   Metric Entries in Section 6. See Section 6.1.2 for mapping to Names.

6.1.2. Name

4: RTDNS_Active_IP-UDP-Poisson_RFC8912sec6_Seconds_Raw

       5: RLDNS_Active_IP-UDP-Poisson_RFC8912sec6_Logical_Raw

6.1.3. URI

   URL: https://www.iana.org/assignments/performance-metrics/
   RTDNS_Active_IP-UDP-Poisson_RFC8912sec6_Seconds_Raw

   URL: https://www.iana.org/assignments/performance-metrics/
   RLDNS_Active_IP-UDP-Poisson_RFC8912sec6_Logical_Raw

6.1.4. Description

   This is a metric for DNS Response performance from a network user's
   perspective, for a specific named resource. The metric can be
   measured repeatedly using different resource names.

   RTDNS: This metric assesses the response time, the interval from the
      query transmission to the response.

   RLDNS: This metric indicates that the response was deemed lost. In
      other words, the response time exceeded the maximum waiting time.

6.1.5. Change Controller

   IETF

6.1.6. Version (of Registry Format)

   1.0

6.2. Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

6.2.1. Reference Definition

   For Delay:

      Mockapetris, P., "Domain names - implementation and
      specification", STD 13, RFC 1035, DOI 10.17487/RFC1035, November
      1987, <https://www.rfc-editor.org/info/rfc1035> (and updates).
      [RFC1035]

      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>. [RFC2681]

Section 2.4 of [RFC2681] provides the reference definition of the singleton (single value) round-trip delay metric. Section 3.4 of [RFC2681] provides the reference definition expanded to cover a multi-singleton sample. Note that terms such as "singleton" and "sample" are defined in Section 11 of [RFC2330].

For DNS Response Latency, the entities in [RFC1035] must be mapped to [RFC2681]. The Local Host with its User Program and Resolver take the Role of "Src", and the Foreign Name Server takes the Role of "Dst".

Note that although the definition of round-trip delay between the Source (Src) and the Destination (Dst) at T as provided in Section 2.4 of [RFC2681] is directionally ambiguous in the text, this metric tightens the definition further to recognize that the host in the Src Role will send the first packet to the host in the Dst Role and will ultimately receive the corresponding return packet from the Dst (when neither is lost).

For Loss:

Morton, A., "Round-Trip Packet Loss Metrics", RFC 6673, DOI 10.17487/RFC6673, August 2012, <https://www.rfc-editor.org/info/rfc6673>. [RFC6673]

For DNS Response Loss, the entities in [RFC1035] must be mapped to [RFC6673]. The Local Host with its User Program and Resolver take the Role of "Src", and the Foreign Name Server takes the Role of "Dst".

Both response time and Loss metrics employ a maximum waiting time for received responses, so the count of lost packets to total packets sent is the basis for the loss determination as per Section 4.3 of [RFC6673].

6.2.2. Fixed Parameters

Type-P as defined in Section 13 of [RFC2330]:
    IPv4 header values:
       DSCP: Set to 0
       TTL: Set to 255
       Protocol: Set to 17 (UDP)

    IPv6 header values:
       DSCP: Set to 0
       Hop Count: Set to 255
       Next Header: Set to 17 (UDP)
       Flow Label: Set to 0
       Extension Headers: None

    UDP header values:

Source port: 53
         Destination port: 53
         Checksum: The checksum MUST be calculated and the non-zero
            checksum included in the header

      Payload:
         The payload contains a DNS message as defined in [RFC1035] with
         the following values:

         The DNS header section contains:
            Identification (see the Runtime column)
            QR: Set to 0 (Query)
            OPCODE: Set to 0 (standard query)
            AA: Not set
            TC: Not set
            RD: Set to 1 (recursion desired)
            RA: Not set
            RCODE: Not set
            QDCOUNT: Set to 1 (only one entry)
            ANCOUNT: Not set
            NSCOUNT: Not set
            ARCOUNT: Not set

         The Question section contains:
            QNAME: The Fully Qualified Domain Name (FQDN) provided as
               input for the test; see the Runtime column

            QTYPE: The query type provided as input for the test; see
               the Runtime column

            QCLASS: Set to 1 for IN

         The other sections do not contain any Resource Records
         (RRs).

   Other measurement Parameters:
      Tmax: A loss threshold waiting time (and to help disambiguate
         queries). The value is 5.0, expressed in units of seconds, as
         a positive value of type decimal64 with fraction digits = 4
         (see Section 9.3 of [RFC6020]) and with a resolution of 0.0001
         seconds (0.1 ms), with lossless conversion to/from the 32-bit
         NTP timestamp as per Section 6 of [RFC5905].

   Observation: Reply packets will contain a DNS Response and may
      contain RRs.

6.3. Method of Measurement

   This category includes columns for references to relevant sections of
   the RFC(s) and any supplemental information needed to ensure an
   unambiguous method for implementations.

. Reference Methods

   The methodology for this metric (equivalent to Type-P-Round-trip-
   Delay-Poisson-Stream) is defined as in Section 2.6 of [RFC2681] (for
   singletons) and Section 3.6 of [RFC2681] (for samples) using the
   Type-P and Timeout defined in the Fixed Parameters column.

   The reference method distinguishes between long-delayed packets and
   lost packets by implementing a maximum waiting time for packet
   arrival. Tmax is the waiting time used as the threshold to declare a
   response packet lost. Lost packets SHALL be designated as having
   undefined delay and counted for the RLDNS metric.

   The calculations on the delay (RTT) SHALL be performed on the
   conditional distribution, conditioned on successful packet arrival
   within Tmax. Also, when all packet delays are stored, the process
   that calculates the RTT value MUST enforce the Tmax threshold on
   stored values before calculations. See Section 4.1 of [RFC3393] for
   details on the conditional distribution to exclude undefined values
   of delay, and see Section 5 of [RFC6703] for background on this
   analysis choice.

   The reference method requires some way to distinguish between
   different packets in a stream to establish correspondence between
   sending times and receiving times for each successfully arriving
   reply.

   DNS messages bearing queries provide for random ID Numbers in the
   Identification header field, so more than one query may be launched
   while a previous request is outstanding when the ID Number is used.
   Therefore, the ID Number MUST be retained at the Src and included
   with each response packet to disambiguate packet reordering if it
   occurs.

   If a DNS Response does not arrive within Tmax, the response time
   RTDNS is undefined, and RLDNS = 1. The Message ID SHALL be used to
   disambiguate the successive queries that are otherwise identical.

   Since the ID Number field is only 16 bits in length, it places a
   limit on the number of simultaneous outstanding DNS queries during a
   stress test from a single Src address.

   Refer to Section 4.4 of [RFC6673] for an expanded discussion of the
   instruction to "send a Type-P packet back to the Src as quickly as
   possible" in Section 2.6 of [RFC2681]. However, the DNS server is
   expected to perform all required functions to prepare and send a
   response, so the response time will include processing time and
   network delay. Section 8 of [RFC6673] presents additional
   requirements that SHALL be included in the Method of Measurement for
   this metric.

In addition to operations described in [RFC2681], the Src MUST parse the DNS headers of the reply and prepare the query response information for subsequent reporting as a measured result, along with the round-trip delay.

6.3.2. Packet Stream Generation

This section provides details regarding packet traffic, which is used as the basis for measurement. In IPPM Metrics, this is called the "stream"; this stream can easily be described by providing the list of stream Parameters.

Section 11.1.3 of [RFC2330] provides three methods to generate Poisson sampling intervals. The reciprocal of lambda is the average packet spacing; thus, the Runtime Parameter is Reciprocal_lambda = 1/lambda, in seconds.

Method 3 SHALL be used. Where given a start time (Runtime Parameter), the subsequent send times are all computed prior to measurement by computing the pseudorandom distribution of inter-packet send times (truncating the distribution as specified in the Parameter Trunc), and the Src sends each packet at the computed times.

Note that Trunc is the upper limit on inter-packet times in the Poisson distribution. A random value greater than Trunc is set equal to Trunc instead.

6.3.3. Traffic Filtering (Observation) Details

N/A

6.3.4. Sampling Distribution

N/A

6.3.5. Runtime Parameters and Data Format

Runtime Parameters are input factors that must be determined, configured into the measurement system, and reported with the results for the context to be complete.

Src: The IP address of the host in the Src Role (format ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value for IPv6; see Section 4 of [RFC6991]).

Dst: The IP address of the host in the Dst Role (format ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value for IPv6; see Section 4 of [RFC6991]).

T0: A time, the start of a measurement interval (format "date-time"
    as specified in [Section 5.6 of [RFC3339]](#); see also "date-and-time"
    in [Section 3 of [RFC6991]](#)). The UTC Time Zone is required by
    [Section 6.1 of [RFC2330]](#). When T0 is "all-zeros", a start time is
    unspecified and Tf is to be interpreted as the duration of the
    measurement interval. The start time is controlled through other
    means.

Tf: A time, the end of a measurement interval (format "date-time" as
    specified in [Section 5.6 of [RFC3339]](#); see also "date-and-time" in
    [Section 3 of [RFC6991]](#)). The UTC Time Zone is required by
    [Section 6.1 of [RFC2330]](#). When T0 is "all-zeros", an ending time
    and date is ignored and Tf is interpreted as the duration of the
    measurement interval.

Reciprocal_lambda: Average packet interval for Poisson streams,
    expressed in units of seconds, as a positive value of type
    decimal64 with fraction digits = 4 (see [Section 9.3 of [RFC6020]](#))
    with a resolution of 0.0001 seconds (0.1 ms), and with lossless
    conversion to/from the 32-bit NTP timestamp as per [Section 6 of
    [RFC5905]](#).

Trunc: Upper limit on Poisson distribution, expressed in units of
    seconds, as a positive value of type decimal64 with fraction
    digits = 4 (see [Section 9.3 of [RFC6020]](#)) with a resolution of
    0.0001 seconds (0.1 ms), and with lossless conversion to/from the
    32-bit NTP timestamp as per [Section 6 of [RFC5905]](#) (values above
    this limit will be clipped and set to the limit value).

ID: The 16-bit Identifier assigned by the program that generates the
    query. The ID value must vary in successive queries (a list of
    IDs is needed); see [Section 4.1.1 of [RFC1035]](#). This Identifier
    is copied into the corresponding reply and can be used by the
    requester (Src) to match replies with any outstanding queries.

QNAME: The domain name of the query, formatted as specified in
    [Section 4 of [RFC6991]](#).

QTYPE: The query type, which will correspond to the IP address
    family of the query (decimal 1 for IPv4 or 28 for IPv6), formatted
    as a uint16, as per [Section 9.2 of [RFC6020]](#).

[6.3.6](#). Roles

Src: Launches each packet and waits for return transmissions from
    the Dst.

Dst: Waits for each packet from the Src and sends a return packet to
    the Src.

[6.4](#). Output

This category specifies all details of the output of measurements using the metric.

6.4.1. Type

   Raw: For each DNS query packet sent, sets of values as defined in the next column, including the status of the response, only assigning delay values to successful query-response pairs.

6.4.2. Reference Definition

   For all outputs:

   T: The time the DNS query was sent during the measurement interval (format "date-time" as specified in Section 5.6 of [RFC3339]; see also "date-and-time" in Section 3 of [RFC6991]). The UTC Time Zone is required by Section 6.1 of [RFC2330].

   dT: The time value of the round-trip delay to receive the DNS Response, expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905]. This value is undefined when the response packet is not received at the Src within a waiting time of Tmax seconds.

   RCODE: The value of the RCODE field in the DNS Response header, expressed as a uint64 as specified in Section 9.2 of [RFC6020]. Non-zero values convey errors in the response, and such replies must be analyzed separately from successful requests.

   Logical: The numeric value of the result is expressed as a Logical value, where 1 = Lost and 0 = Received, as a positive value of type uint8 (represents integer values between 0 and 255, inclusively (see Section 9.2 of [RFC6020]). Note that for queries with outcome 1 = Lost, dT and RCODE will be set to the maximum for decimal64 and uint64, respectively.

6.4.3. Metric Units

   RTDNS: Round-trip delay, dT, is expressed in seconds.

   RLDNS: The Logical value, where 1 = Lost and 0 = Received.

6.4.4. Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the systematic and random errors of a time measurement. Calibration in-situ could be enabled with an internal loopback at the Source host

that includes as much of the measurement system as possible, performs
address and payload manipulation as needed, and provides some form of
isolation (e.g., deterministic delay) to avoid send-receive interface
contention. Some portion of the random and systematic error can be
characterized in this way.

When a measurement controller requests a calibration measurement, the
loopback is applied and the result is output in the same format as a
normal measurement, with an additional indication that it is a
calibration result.

Both internal loopback calibration and clock synchronization can be
used to estimate the available accuracy of the Output Metric Units.
For example, repeated loopback delay measurements will reveal the
portion of the output result resolution that is the result of system
noise and is thus inaccurate.

6.5. Administrative Items

6.5.1. Status

Current

6.5.2. Requester

RFC 8912

6.5.3. Revision

1.0

6.5.4. Revision Date

2021-11-17

6.6. Comments and Remarks

None

7. UDP Poisson One-Way Delay and Loss Registry Entries

This section specifies five initial Registry Entries for UDP Poisson
One-Way Delay and one entry for UDP Poisson One-Way Loss.

All column entries besides the ID, Name, Description, and Output
Reference Method categories are the same; thus, this section defines
six closely related Registry Entries. As a result, IANA has assigned
corresponding URLs to each of the Named Metrics.

7.1. Summary

This category includes multiple indexes to the Registry Entries: the element ID and Metric Name.

7.1.1. ID (Identifier)

IANA has allocated the numeric Identifiers 6-11 for the six Named Metric Entries in Section 7. See Section 7.1.2 for mapping to Names.

7.1.2. Name

6:
     OWDelay_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Seconds_95Percentile

7:   OWDelay_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Seconds_Mean

8:   OWDelay_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Seconds_Min

9:   OWDelay_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Seconds_Max

10:
     OWDelay_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Seconds_StdDev

11:
     OWLoss_Active_IP-UDP-Poisson-
     Payload250B_RFC8912sec7_Percent_LossRatio

7.1.3. URI

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Poisson-
Payload250B_RFC8912sec7_Seconds_95Percentile

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Poisson-Payload250B_RFC8912sec7_Seconds_Mean

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Poisson-Payload250B_RFC8912sec7_Seconds_Min

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Poisson-Payload250B_RFC8912sec7_Seconds_Max

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Poisson-Payload250B_RFC8912sec7_Seconds_StdDev

URL: https://www.iana.org/assignments/performance-metrics/
OWLoss_Active_IP-UDP-Poisson-

Payload250B_RFC8912sec7_Percent_LossRatio

7.1.4. Description

   OWDelay: This metric assesses the delay of a stream of packets
      exchanged between two hosts (or measurement points) and reports
      the <statistic> of one-way delay for all successfully exchanged
      packets based on their conditional delay distribution.

      where <statistic> is one of:

      * 95Percentile

      * Mean

      * Min

      * Max

      * StdDev

   OWLoss: This metric assesses the loss ratio of a stream of packets
      exchanged between two hosts (which are the two measurement
      points). The output is the one-way loss ratio for all transmitted
      packets expressed as a percentage.

7.1.5. Change Controller

   IETF

7.1.6. Version (of Registry Format)

   1.0

7.2. Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

7.2.1. Reference Definition

   For delay:

      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>. [RFC7679]

      Morton, A. and E. Stephan, "Spatial Composition of Metrics", RFC
      6049, DOI 10.17487/RFC6049, January 2011, <https://www.rfc-

editor.org/info/rfc6049>. [RFC6049]

Section 3.4 of [RFC7679] provides the reference definition of the
singleton (single value) one-way delay metric. Section 4.4 of
[RFC7679] provides the reference definition expanded to cover a
multi-value sample. Note that terms such as "singleton" and
"sample" are defined in Section 11 of [RFC2330].

Only successful packet transfers with finite delay are included in
the sample, as prescribed in Section 4.1.2 of [RFC6049].

   For loss:

Almes, G., Kalidindi, S., Zekauskas, M., and A. Morton, Ed., "A
One-Way Loss Metric for IP Performance Metrics (IPPM)", STD 82,
RFC 7680, DOI 10.17487/RFC7680, January 2016, <https://www.rfc-
editor.org/info/rfc7680>. [RFC7680]

Section 2.4 of [RFC7680] provides the reference definition of the
singleton (single value) one-way Loss metric. Section 3.4 of
[RFC7680] provides the reference definition expanded to cover a
multi-singleton sample. Note that terms such as "singleton" and
"sample" are defined in Section 11 of [RFC2330].

7.2.2. Fixed Parameters

   Type-P:
      IPv4 header values:
         DSCP: Set to 0
         TTL: Set to 255
         Protocol: Set to 17 (UDP)

      IPv6 header values:
         DSCP: Set to 0
         Hop Count: Set to 255
         Next Header: Set to 17 (UDP)
         Flow Label: Set to 0
         Extension Headers: None

      UDP header values:
         Checksum: The checksum MUST be calculated and the non-zero
            checksum included in the header

      UDP Payload: TWAMP-Test packet formats (Section 4.1.2 of
         [RFC5357])

            Security features in use influence the number of Padding
            octets

            250 octets total, including the TWAMP format type, which
            MUST be reported

Other measurement Parameters:
    Tmax: A loss threshold waiting time with value 3.0, expressed in
        units of seconds, as a positive value of type decimal64 with
        fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a
        resolution of 0.0001 seconds (0.1 ms), with lossless conversion
        to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

    See the Packet Stream Generation section for two additional Fixed
    Parameters.

7.3. Method of Measurement

    This category includes columns for references to relevant sections of
    the RFC(s) and any supplemental information needed to ensure an
    unambiguous method for implementations.

7.3.1. Reference Methods

    The methodology for this metric (equivalent to Type-P-One-way-Delay-
    Poisson-Stream) is defined as in Section 3.6 of [RFC7679] (for
    singletons) and Section 4.6 of [RFC7679] (for samples) using the
    Type-P and Tmax defined in the Fixed Parameters column.

    The reference method distinguishes between long-delayed packets and
    lost packets by implementing a maximum waiting time for packet
    arrival. Tmax is the waiting time used as the threshold to declare a
    packet lost. Lost packets SHALL be designated as having undefined
    delay and counted for the OWLoss metric.

    The calculations on the one-way delay SHALL be performed on the
    conditional distribution, conditioned on successful packet arrival
    within Tmax. Also, when all packet delays are stored, the process
    that calculates the one-way delay value MUST enforce the Tmax
    threshold on stored values before calculations. See Section 4.1 of
    [RFC3393] for details on the conditional distribution to exclude
    undefined values of delay, and see Section 5 of [RFC6703] for
    background on this analysis choice.

    The reference method requires some way to distinguish between
    different packets in a stream to establish correspondence between
    sending times and receiving times for each successfully arriving
    packet.

    Since a standard measurement protocol is employed [RFC5357], the
    measurement process will determine the sequence numbers or timestamps
    applied to test packets after the Fixed and Runtime Parameters are
    passed to that process. The measurement protocol dictates the format
    of sequence numbers and timestamps conveyed in the TWAMP-Test packet
    payload.

7.3.2. Packet Stream Generation

   This section provides details regarding packet traffic, which is used
   as the basis for measurement. In IPPM Metrics, this is called the
   "stream"; this stream can easily be described by providing the list
   of stream Parameters.

   Section 11.1.3 of [RFC2330] provides three methods to generate
   Poisson sampling intervals. The reciprocal of lambda is the average
   packet spacing; thus, the Runtime Parameter is
   Reciprocal_lambda = 1/lambda, in seconds.

   Method 3 SHALL be used. Where given a start time (Runtime
   Parameter), the subsequent send times are all computed prior to
   measurement by computing the pseudorandom distribution of inter-
   packet send times (truncating the distribution as specified in the
   Parameter Trunc), and the Src sends each packet at the computed
   times.

   Note that Trunc is the upper limit on inter-packet times in the
   Poisson distribution. A random value greater than Trunc is set equal
   to Trunc instead.

   Reciprocal_lambda: Average packet interval for Poisson streams,
      expressed in units of seconds, as a positive value of type
      decimal64 with fraction digits = 4 (see Section 9.3 of [RFC6020])
      with a resolution of 0.0001 seconds (0.1 ms), and with lossless
      conversion to/from the 32-bit NTP timestamp as per Section 6 of
      [RFC5905]. Reciprocal_lambda = 1 second.

   Trunc: Upper limit on Poisson distribution, expressed in units of
      seconds, as a positive value of type decimal64 with fraction
      digits = 4 (see Section 9.3 of [RFC6020]) with a resolution of
      0.0001 seconds (0.1 ms), and with lossless conversion to/from the
      32-bit NTP timestamp as per Section 6 of [RFC5905] (values above
      this limit will be clipped and set to the limit value).
      Trunc = 30.0000 seconds.

7.3.3. Traffic Filtering (Observation) Details

   N/A

7.3.4. Sampling Distribution

   N/A

7.3.5. Runtime Parameters and Data Format

   Runtime Parameters are input factors that must be determined,
   configured into the measurement system, and reported with the results
   for the context to be complete.

Src: The IP address of the host in the Src Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see [Section 4 of [RFC6991]](#)).

Dst: The IP address of the host in the Dst Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see [Section 4 of [RFC6991]](#)).

T0:   A time, the start of a measurement interval (format "date-time"
      as specified in [Section 5.6 of [RFC3339]](#); see also "date-and-time"
      in [Section 3 of [RFC6991]](#)). The UTC Time Zone is required by
      [Section 6.1 of [RFC2330]](#). When T0 is "all-zeros", a start time is
      unspecified and Tf is to be interpreted as the duration of the
      measurement interval. The start time is controlled through other
      means.

Tf: A time, the end of a measurement interval (format "date-time" as
      specified in [Section 5.6 of [RFC3339]](#); see also "date-and-time" in
      [Section 3 of [RFC6991]](#)). The UTC Time Zone is required by
      [Section 6.1 of [RFC2330]](#). When T0 is "all-zeros", an ending time
      and date is ignored and Tf is interpreted as the duration of the
      measurement interval.

7.3.6. Roles

Src: Launches each packet and waits for return transmissions from
      the Dst. An example is the TWAMP Session-Sender.

Dst: Waits for each packet from the Src and sends a return packet to
      the Src. An example is the TWAMP Session-Reflector.

7.4. Output

This category specifies all details of the output of measurements
using the metric.

7.4.1. Type

Types are discussed in the subsections below.

7.4.2. Reference Definition

For all output types:

T0:   The start of a measurement interval (format "date-time" as
      specified in [Section 5.6 of [RFC3339]](#); see also "date-and-time" in
      [Section 3 of [RFC6991]](#)). The UTC Time Zone is required by
      [Section 6.1 of [RFC2330]](#).

Tf: The end of a measurement interval (format "date-time" as

specified in Section 5.6 of [RFC3339]; see also "date-and-time" in Section 3 of [RFC6991]). The UTC Time Zone is required by Section 6.1 of [RFC2330].

For LossRatio, the count of lost packets to total packets sent is the basis for the loss ratio calculation as per Section 4.1 of [RFC7680].

For each <statistic> or Percent_LossRatio, one of the following subsections applies.

7.4.2.1. Percentile95

The 95th percentile SHALL be calculated using the conditional distribution of all packets with a finite value of one-way delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.3 of [RFC3393] for details on the percentile statistic (where round-trip delay should be substituted for "ipdv").

The percentile = 95, meaning that the reported delay, "95Percentile", is the smallest value of one-way delay for which the Empirical Distribution Function, EDF(95Percentile), is greater than or equal to 95% of the singleton one-way delay values in the conditional distribution. See Section 11.3 of [RFC2330] for the definition of the percentile statistic using the EDF.

95Percentile: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

7.4.2.2. Mean

The mean SHALL be calculated using the conditional distribution of all packets with a finite value of one-way delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.2.2 of [RFC6049] for details on calculating this statistic; see also Section 4.2.3 of [RFC6049].

Mean: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9

(see [Section 9.3 of [RFC6020]](#)) with a resolution of
0.000000001 seconds (1.0 ns), and with lossless conversion to/from
the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

[7.4.2.3](#). Min

   The minimum SHALL be calculated using the conditional distribution of
   all packets with a finite value of one-way delay (undefined delays
   are excluded) -- a single value, as follows:

   See [Section 4.1 of [RFC3393]](#) for details on the conditional
   distribution to exclude undefined values of delay, and see [Section 5
   of [RFC6703]](#) for background on this analysis choice.

   See [Section 4.3.2 of [RFC6049]](#) for details on calculating this
   statistic; see also [Section 4.3.3 of [RFC6049]](#).

   Min: The time value of the result is expressed in units of seconds,
      as a positive value of type decimal64 with fraction digits = 9
      (see [Section 9.3 of [RFC6020]](#)) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

[7.4.2.4](#). Max

   The maximum SHALL be calculated using the conditional distribution of
   all packets with a finite value of one-way delay (undefined delays
   are excluded) -- a single value, as follows:

   See [Section 4.1 of [RFC3393]](#) for details on the conditional
   distribution to exclude undefined values of delay, and see [Section 5
   of [RFC6703]](#) for background on this analysis choice.

   See [Section 4.3.2 of [RFC6049]](#) for a closely related method for
   calculating this statistic; see also [Section 4.3.3 of [RFC6049]](#). The
   formula is as follows:

      Max = (FiniteDelay[j])

      such that for some index, j, where 1 <= j <= N
      FiniteDelay[j] >= FiniteDelay[n] for all n

   Max: The time value of the result is expressed in units of seconds,
      as a positive value of type decimal64 with fraction digits = 9
      (see [Section 9.3 of [RFC6020]](#)) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

[7.4.2.5](#). Std_Dev

   The standard deviation (Std_Dev) SHALL be calculated using the

conditional distribution of all packets with a finite value of
one-way delay (undefined delays are excluded) -- a single value, as
follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

See Section 6.1.4 of [RFC6049] for a closely related method for
calculating this statistic. The formula is the classic calculation
for the standard deviation of a population.

Define Population Std_Dev_Delay as follows:

$$
Std\_Dev = SQRT \left[\frac{1}{(N)} \sum_{n=1}^{N} (Delay[n] - MeanDelay)^2 \right]
$$

where all packets n = 1 through N have a value for Delay[n],
MeanDelay is calculated per Section 7.4.2.2, and SQRT[] is the Square
Root function:

Std_Dev: The time value of the result is expressed in units of
   seconds, as a positive value of type decimal64 with fraction
   digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
   0.000000001 seconds (1.0 ns), and with lossless conversion to/from
   the 64-bit NTP timestamp as per Section 6 of [RFC5905].

7.4.2.6. Percent_LossRatio

Percent_LossRatio: The numeric value of the result is expressed in
   units of lost packets to total packets times 100%, as a positive
   value of type decimal64 with fraction digits = 9 (see Section 9.3
   of [RFC6020]) with a resolution of 0.0000000001.

7.4.3. Metric Units

The <statistic> of one-way delay is expressed in seconds, where
<statistic> is one of:

* 95Percentile

* Mean

* Min

* Max

   * StdDev

   The one-way loss ratio is expressed as a percentage of lost packets
   to total packets sent.

7.4.4. Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the
   systematic and random errors of a time measurement. Calibration in-
   situ could be enabled with an internal loopback that includes as much
   of the measurement system as possible, performs address manipulation
   as needed, and provides some form of isolation (e.g., deterministic
   delay) to avoid send-receive interface contention. Some portion of
   the random and systematic error can be characterized in this way.

   For one-way delay measurements, the error calibration must include an
   assessment of the internal clock synchronization with its external
   reference (this internal clock is supplying timestamps for
   measurement). In practice, the time offsets [RFC5905] of clocks at
   both the Source and Destination are needed to estimate the systematic
   error due to imperfect clock synchronization (the time offsets
   [RFC5905] are smoothed; thus, the random variation is not usually
   represented in the results).

   time_offset: The time value of the result is expressed in units of
      seconds, as a signed value of type decimal64 with fraction
      digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per Section 6 of [RFC5905].

   When a measurement controller requests a calibration measurement, the
   loopback is applied and the result is output in the same format as a
   normal measurement, with an additional indication that it is a
   calibration result. In any measurement, the measurement function
   SHOULD report its current estimate of the time offset [RFC5905] as an
   indicator of the degree of synchronization.

   Both internal loopback calibration and clock synchronization can be
   used to estimate the available accuracy of the Output Metric Units.
   For example, repeated loopback delay measurements will reveal the
   portion of the output result resolution that is the result of system
   noise and is thus inaccurate.

7.5. Administrative Items

7.5.1. Status

   Current

7.5.2. Requester

   [RFC 8912](#)

7.5.3. Revision

   1.0

7.5.4. Revision Date

   2021-11-17

7.6. Comments and Remarks

   None

8. UDP Periodic One-Way Delay and Loss Registry Entries

   This section specifies five initial Registry Entries for UDP Periodic
   One-Way Delay and one entry for UDP Periodic One-Way Loss.

   All column entries besides the ID, Name, Description, and Output
   Reference Method categories are the same; thus, this section defines
   six closely related Registry Entries. As a result, IANA has assigned
   corresponding URLs to each of the six Named Metrics.

8.1. Summary

   This category includes multiple indexes to the Registry Entries: the
   element ID and Metric Name.

8.1.1. ID (Identifier)

   IANA has allocated the numeric Identifiers 12-17 for the six Named
   Metric Entries in [Section 8](#). See [Section 8.1.2](#) for mapping to Names.

8.1.2. Name

   12:
       OWDelay_Active_IP-UDP-Periodic20m-
       Payload142B_RFC8912sec8_Seconds_95Percentile

   13:
       OWDelay_Active_IP-UDP-Periodic20m-
       Payload142B_RFC8912sec8_Seconds_Mean

   14:
       OWDelay_Active_IP-UDP-Periodic20m-
       Payload142B_RFC8912sec8_Seconds_Min

15:
  OWDelay_Active_IP-UDP-Periodic20m-
  Payload142B_RFC8912sec8_Seconds_Max

16:
  OWDelay_Active_IP-UDP-Periodic20m-
  Payload142B_RFC8912sec8_Seconds_StdDev

17:
  OWLoss_Active_IP-UDP-Periodic20m-
  Payload142B_RFC8912sec8_Percent_LossRatio

8.1.3. URI

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Periodic20m-
Payload142B_RFC8912sec8_Seconds_95Percentile

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Periodic20m-
Payload142B_RFC8912sec8_Seconds_Mean

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Periodic20m-Payload142B_RFC8912sec8_Seconds_Min

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Periodic20m-Payload142B_RFC8912sec8_Seconds_Max

URL: https://www.iana.org/assignments/performance-metrics/
OWDelay_Active_IP-UDP-Periodic20m-
Payload142B_RFC8912sec8_Seconds_StdDev

URL: https://www.iana.org/assignments/performance-metrics/
OWLoss_Active_IP-UDP-Periodic20m-
Payload142B_RFC8912sec8_Percent_LossRatio

8.1.4. Description

OWDelay: This metric assesses the delay of a stream of packets
   exchanged between two hosts (or measurement points) and reports
   the <statistic> of one-way delay for all successfully exchanged
   packets based on their conditional delay distribution.

   where <statistic> is one of:

   * 95Percentile

   * Mean

   * Min

* Max

   * StdDev

   OWLoss: This metric assesses the loss ratio of a stream of packets
      exchanged between two hosts (which are the two measurement
      points). The output is the one-way loss ratio for all transmitted
      packets expressed as a percentage.

8.1.5. Change Controller

   IETF

8.1.6. Version (of Registry Format)

   1.0

8.2. Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

8.2.1. Reference Definition

   For delay:

      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>. [RFC7679]

      Morton, A. and E. Stephan, "Spatial Composition of Metrics", RFC
      6049, DOI 10.17487/RFC6049, January 2011, <https://www.rfc-
      editor.org/info/rfc6049>. [RFC6049]

      Section 3.4 of [RFC7679] provides the reference definition of the
      singleton (single value) one-way delay metric. Section 4.4 of
      [RFC7679] provides the reference definition expanded to cover a
      multi-value sample. Note that terms such as "singleton" and
      "sample" are defined in Section 11 of [RFC2330].

      Only successful packet transfers with finite delay are included in
      the sample, as prescribed in Section 4.1.2 of [RFC6049].

   For loss:

      Almes, G., Kalidindi, S., Zekauskas, M., and A. Morton, Ed., "A
      One-Way Loss Metric for IP Performance Metrics (IPPM)", STD 82,
      RFC 7680, DOI 10.17487/RFC7680, January 2016, <https://www.rfc-
      editor.org/info/rfc7680>. [RFC7680]

Section 2.4 of [RFC7680] provides the reference definition of the singleton (single value) one-way Loss metric. Section 3.4 of [RFC7680] provides the reference definition expanded to cover a multi-singleton sample. Note that terms such as "singleton" and "sample" are defined in Section 11 of [RFC2330].

8.2.2. Fixed Parameters

   Type-P:
      IPv4 header values:
         DSCP: Set to 0
         TTL: Set to 255
         Protocol: Set to 17 (UDP)

      IPv6 header values:
         DSCP: Set to 0
         Hop Count: Set to 255
         Next Header: Set to 17 (UDP)
         Flow Label: Set to 0
         Extension Headers: None

      UDP header values:
         Checksum: The checksum MUST be calculated and the non-zero
            checksum included in the header

      UDP Payload: TWAMP-Test packet formats (Section 4.1.2 of
         [RFC5357])

            Security features in use influence the number of Padding
            octets

            142 octets total, including the TWAMP format (and format
            type MUST be reported, if used)

   Other measurement Parameters:
      Tmax: A loss threshold waiting time with value 3.0, expressed in
         units of seconds, as a positive value of type decimal64 with
         fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a
         resolution of 0.0001 seconds (0.1 ms), with lossless conversion
         to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

   See the Packet Stream Generation section for three additional Fixed
   Parameters.

8.3. Method of Measurement

   This category includes columns for references to relevant sections of
   the RFC(s) and any supplemental information needed to ensure an
   unambiguous method for implementations.

8.3.1. Reference Methods

The methodology for this metric (equivalent to Type-P-One-way-Delay-Poisson-Stream) is defined as in Section 3.6 of [RFC7679] (for singletons) and Section 4.6 of [RFC7679] (for samples) using the Type-P and Tmax defined in the Fixed Parameters column. However, a Periodic stream is used, as defined in [RFC3432].

The reference method distinguishes between long-delayed packets and lost packets by implementing a maximum waiting time for packet arrival. Tmax is the waiting time used as the threshold to declare a packet lost. Lost packets SHALL be designated as having undefined delay and counted for the OWLoss metric.

The calculations on the one-way delay SHALL be performed on the conditional distribution, conditioned on successful packet arrival within Tmax. Also, when all packet delays are stored, the process that calculates the one-way delay value MUST enforce the Tmax threshold on stored values before calculations. See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

The reference method requires some way to distinguish between different packets in a stream to establish correspondence between sending times and receiving times for each successfully arriving packet.

Since a standard measurement protocol is employed [RFC5357], the measurement process will determine the sequence numbers or timestamps applied to test packets after the Fixed and Runtime Parameters are passed to that process. The measurement protocol dictates the format of sequence numbers and timestamps conveyed in the TWAMP-Test packet payload.

8.3.2. Packet Stream Generation

This section provides details regarding packet traffic, which is used as the basis for measurement. In IPPM Metrics, this is called the "stream"; this stream can easily be described by providing the list of stream Parameters.

Section 3 of [RFC3432] prescribes the method for generating Periodic streams using associated Parameters.

incT: The nominal duration of the inter-packet interval, first bit to first bit, with value 0.0200, expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms), with lossless conversion to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

dT: The duration of the interval for allowed sample start times,
     with value 1.0000, expressed in units of seconds, as a positive
     value of type decimal64 with fraction digits = 4 (see Section 9.3
     of [RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms),
     with lossless conversion to/from the 32-bit NTP timestamp as per
     Section 6 of [RFC5905].

T0: The actual start time of the periodic stream, determined from T0
     and dT.

     Note: An initiation process with a number of control exchanges
     resulting in unpredictable start times (within a time interval)
     may be sufficient to avoid synchronization of periodic streams and
     is a valid replacement for selecting a start time at random from a
     fixed interval.

   These stream Parameters will be specified as Runtime Parameters.

8.3.3. Traffic Filtering (Observation) Details

   N/A

8.3.4. Sampling Distribution

   N/A

8.3.5. Runtime Parameters and Data Format

   Runtime Parameters are input factors that must be determined,
   configured into the measurement system, and reported with the results
   for the context to be complete.

Src: The IP address of the host in the Src Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see Section 4 of [RFC6991]).

Dst: The IP address of the host in the Dst Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see Section 4 of [RFC6991]).

T0: A time, the start of a measurement interval (format "date-time"
     as specified in Section 5.6 of [RFC3339]; see also "date-and-time"
     in Section 3 of [RFC6991]). The UTC Time Zone is required by
     Section 6.1 of [RFC2330]. When T0 is "all-zeros", a start time is
     unspecified and Tf is to be interpreted as the duration of the
     measurement interval. The start time is controlled through other
     means.

Tf: A time, the end of a measurement interval (format "date-time" as
     specified in Section 5.6 of [RFC3339]; see also "date-and-time" in

Section 3 of [RFC6991]). The UTC Time Zone is required by
Section 6.1 of [RFC2330]. When T0 is "all-zeros", an ending time
and date is ignored and Tf is interpreted as the duration of the
measurement interval.

8.3.6. Roles

Src: Launches each packet and waits for return transmissions from
the Dst. An example is the TWAMP Session-Sender.

Dst: Waits for each packet from the Src and sends a return packet to
the Src. An example is the TWAMP Session-Reflector.

8.4. Output

This category specifies all details of the output of measurements
using the metric.

8.4.1. Type

Latency and Loss Types are discussed in the subsections below.

8.4.2. Reference Definition

For all output types:

T0: The start of a measurement interval (format "date-time" as
specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
Section 3 of [RFC6991]). The UTC Time Zone is required by
Section 6.1 of [RFC2330].

Tf: The end of a measurement interval (format "date-time" as
specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
Section 3 of [RFC6991]). The UTC Time Zone is required by
Section 6.1 of [RFC2330].

For LossRatio, the count of lost packets to total packets sent is the
basis for the loss ratio calculation as per Section 4.1 of [RFC7680].

For each <statistic> or Percent_LossRatio, one of the following
subsections applies.

8.4.2.1. Percentile95

The 95th percentile SHALL be calculated using the conditional
distribution of all packets with a finite value of one-way delay
(undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

See Section 4.3 of [RFC3393] for details on the percentile statistic (where round-trip delay should be substituted for "ipdv").

The percentile = 95, meaning that the reported delay, "95Percentile", is the smallest value of one-way delay for which the Empirical Distribution Function, EDF(95Percentile), is greater than or equal to 95% of the singleton one-way delay values in the conditional distribution. See Section 11.3 of [RFC2330] for the definition of the percentile statistic using the EDF.

95Percentile: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

8.4.2.2. Mean

The mean SHALL be calculated using the conditional distribution of all packets with a finite value of one-way delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.2.2 of [RFC6049] for details on calculating this statistic; see also Section 4.2.3 of [RFC6049].

Mean: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

8.4.2.3. Min

The minimum SHALL be calculated using the conditional distribution of all packets with a finite value of one-way delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.3.2 of [RFC6049] for details on calculating this statistic; see also Section 4.3.3 of [RFC6049].

Min: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9

(see [Section 9.3 of [RFC6020]](#)) with a resolution of
0.000000001 seconds (1.0 ns), and with lossless conversion to/from
the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

[8.4.2.4](#). Max

The maximum SHALL be calculated using the conditional distribution of
all packets with a finite value of one-way delay (undefined delays
are excluded) -- a single value, as follows:

See [Section 4.1 of [RFC3393]](#) for details on the conditional
distribution to exclude undefined values of delay, and see [Section 5
of [RFC6703]](#) for background on this analysis choice.

See [Section 4.3.2 of [RFC6049]](#) for a closely related method for
calculating this statistic; see also [Section 4.3.3 of [RFC6049]](#). The
formula is as follows:

    Max = (FiniteDelay[j])

    such that for some index, j, where 1 <= j <= N
    FiniteDelay[j] >= FiniteDelay[n] for all n

Max: The time value of the result is expressed in units of seconds,
   as a positive value of type decimal64 with fraction digits = 9
   (see [Section 9.3 of [RFC6020]](#)) with a resolution of
   0.000000001 seconds (1.0 ns), and with lossless conversion to/from
   the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

[8.4.2.5](#). Std_Dev

Std_Dev SHALL be calculated using the conditional distribution of all
packets with a finite value of one-way delay (undefined delays are
excluded) -- a single value, as follows:

See [Section 4.1 of [RFC3393]](#) for details on the conditional
distribution to exclude undefined values of delay, and see [Section 5
of [RFC6703]](#) for background on this analysis choice.

See [Section 6.1.4 of [RFC6049]](#) for a closely related method for
calculating this statistic. The formula is the classic calculation
for the standard deviation of a population.

Define Population Std_Dev_Delay as follows:

$$
\text{Std\_Dev} = \text{SQRT} \left[\frac{1}{N} \sum_{n=1}^{N} (\text{Delay}[n] - \text{MeanDelay})^2 \right]
$$

```
                |                ---                         |
                |              n = 1                         |
                |_                                         _|
```

   where all packets n = 1 through N have a value for Delay[n],
   MeanDelay is calculated per Section 8.4.2.2, and SQRT[] is the Square
   Root function:

   Std_Dev: The time value of the result is expressed in units of
      seconds, as a positive value of type decimal64 with fraction
      digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per Section 6 of [RFC5905].

8.4.2.6. Percent_LossRatio

   Percent_LossRatio: The numeric value of the result is expressed in
      units of lost packets to total packets times 100%, as a positive
      value of type decimal64 with fraction digits = 9 (see Section 9.3
      of [RFC6020] with a resolution of 0.0000000001.

8.4.3. Metric Units

   The <statistic> of one-way delay is expressed in seconds, where
   <statistic> is one of:

   * 95Percentile

   * Mean

   * Min

   * Max

   * StdDev

   The one-way loss ratio is expressed as a percentage of lost packets
   to total packets sent.

8.4.4. Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the
   systematic and random errors of a time measurement. Calibration in-
   situ could be enabled with an internal loopback that includes as much
   of the measurement system as possible, performs address manipulation
   as needed, and provides some form of isolation (e.g., deterministic
   delay) to avoid send-receive interface contention. Some portion of
   the random and systematic error can be characterized in this way.

   For one-way delay measurements, the error calibration must include an
   assessment of the internal clock synchronization with its external
```

reference (this internal clock is supplying timestamps for measurement).  In practice, the time offsets [RFC5905] of clocks at both the Source and Destination are needed to estimate the systematic error due to imperfect clock synchronization (the time offsets [RFC5905] are smoothed; thus, the random variation is not usually represented in the results).

time_offset:  The time value of the result is expressed in units of seconds, as a signed value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

When a measurement controller requests a calibration measurement, the loopback is applied and the result is output in the same format as a normal measurement, with an additional indication that it is a calibration result.  In any measurement, the measurement function SHOULD report its current estimate of the time offset [RFC5905] as an indicator of the degree of synchronization.

Both internal loopback calibration and clock synchronization can be used to estimate the available accuracy of the Output Metric Units.  For example, repeated loopback delay measurements will reveal the portion of the output result resolution that is the result of system noise and is thus inaccurate.

## 8.5.  Administrative Items

### 8.5.1.  Status

Current

### 8.5.2.  Requester

RFC 8912

### 8.5.3.  Revision

1.0

### 8.5.4.  Revision Date

2021-11-17

## 8.6.  Comments and Remarks

None

# 9.  ICMP Round-Trip Latency and Loss Registry Entries

This section specifies three initial Registry Entries for ICMP

Round-Trip Latency and another entry for the ICMP Round-Trip Loss
Ratio.

All column entries besides the ID, Name, Description, and Output
Reference Method categories are the same; thus, this section defines
four closely related Registry Entries.  As a result, IANA has
assigned corresponding URLs to each of the four Named Metrics.

## 9.1.  Summary

This category includes multiple indexes to the Registry Entries: the
element ID and Metric Name.

### 9.1.1.  ID (Identifier)

IANA has allocated the numeric Identifiers 18-21 for the four Named
Metric Entries in Section 9.  See Section 9.1.2 for mapping to Names.

### 9.1.2.  Name

18:  RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Mean

19:  RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Min

20:  RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Max

21:  RTLoss_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Percent_LossRatio

### 9.1.3.  URI

URL:  https://www.iana.org/assignments/performance-metrics/
RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Mean

URL:  https://www.iana.org/assignments/performance-metrics/
RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Min

URL:  https://www.iana.org/assignments/performance-metrics/
RTDelay_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Seconds_Max

URL:  https://www.iana.org/assignments/performance-metrics/
RTLoss_Active_IP-ICMP-SendOnRcv_RFC8912sec9_Percent_LossRatio

### 9.1.4.  Description

RTDelay:  This metric assesses the delay of a stream of ICMP packets
   exchanged between two hosts (which are the two measurement
   points).  The output is the round-trip delay for all successfully
   exchanged packets expressed as the <statistic> of their
   conditional delay distribution, where <statistic> is one of:

   *  Mean

*  Min

   *  Max

   RTLoss:  This metric assesses the loss ratio of a stream of ICMP
      packets exchanged between two hosts (which are the two measurement
      points).  The output is the round-trip loss ratio for all
      transmitted packets expressed as a percentage.

## 9.1.5.  Change Controller

   IETF

## 9.1.6.  Version (of Registry Format)

   1.0

## 9.2.  Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

## 9.2.1.  Reference Definition

   For delay:

      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>.  [RFC2681]

      Section 2.4 of [RFC2681] provides the reference definition of the
      singleton (single value) round-trip delay metric.  Section 3.4 of
      [RFC2681] provides the reference definition expanded to cover a
      multi-singleton sample.  Note that terms such as "singleton" and
      "sample" are defined in Section 11 of [RFC2330].

      Note that although the definition of round-trip delay between the
      Source (Src) and the Destination (Dst) as provided in Section 2.4
      of [RFC2681] is directionally ambiguous in the text, this metric
      tightens the definition further to recognize that the host in the
      Src Role will send the first packet to the host in the Dst Role
      and will ultimately receive the corresponding return packet from
      the Dst (when neither is lost).

      Finally, note that the variable "dT" is used in [RFC2681] to refer
      to the value of round-trip delay in metric definitions and
      methods.  The variable "dT" has been reused in other IPPM
      literature to refer to different quantities and cannot be used as
      a global variable name.

For loss:

   Morton, A., "Round-Trip Packet Loss Metrics", RFC 6673, DOI
   10.17487/RFC6673, August 2012, <https://www.rfc-editor.org/info/
   rfc6673>.  [RFC6673]

Both Delay and Loss metrics employ a maximum waiting time for
received packets, so the count of lost packets to total packets sent
is the basis for the loss ratio calculation as per Section 6.1 of
[RFC6673].

## 9.2.2.  Fixed Parameters

Type-P as defined in Section 13 of [RFC2330]:
   IPv4 header values:
      DSCP:  Set to 0
      TTL:  Set to 255
      Protocol:  Set to 01 (ICMP)

   IPv6 header values:
      DSCP:  Set to 0
      Hop Count:  Set to 255
      Next Header:  Set to 128 decimal (ICMP)
      Flow Label:  Set to 0
      Extension Headers:  None

   ICMP header values:
      Type:  8 (Echo Request)
      Code:  0
      Checksum:  The checksum MUST be calculated and the non-zero
         checksum included in the header
      (Identifier and sequence number set at runtime)

   ICMP Payload:
      Total of 32 bytes of random information, constant per test

Other measurement Parameters:
   Tmax:  A loss threshold waiting time with value 3.0, expressed in
      units of seconds, as a positive value of type decimal64 with
      fraction digits = 4 (see Section 9.3 of [RFC6020]) and with a
      resolution of 0.0001 seconds (0.1 ms), with lossless conversion
      to/from the 32-bit NTP timestamp as per Section 6 of [RFC5905].

## 9.3.  Method of Measurement

This category includes columns for references to relevant sections of
the RFC(s) and any supplemental information needed to ensure an
unambiguous method for implementations.

## 9.3.1.  Reference Methods

The methodology for this metric (equivalent to Type-P-Round-trip-Delay-Poisson-Stream) is defined as in Section 2.6 of [RFC2681] (for singletons) and Section 3.6 of [RFC2681] (for samples) using the Type-P and Tmax defined in the Fixed Parameters column.

The reference method distinguishes between long-delayed packets and lost packets by implementing a maximum waiting time for packet arrival.  Tmax is the waiting time used as the threshold to declare a packet lost.  Lost packets SHALL be designated as having undefined delay and counted for the RTLoss metric.

The calculations on the delay (RTD) SHALL be performed on the conditional distribution, conditioned on successful packet arrival within Tmax.  Also, when all packet delays are stored, the process that calculates the RTD value MUST enforce the Tmax threshold on stored values before calculations.  See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

The reference method requires some way to distinguish between different packets in a stream to establish correspondence between sending times and receiving times for each successfully arriving packet.  Sequence numbers or other send-order identification MUST be retained at the Src or included with each packet to disambiguate packet reordering if it occurs.

The measurement process will determine the sequence numbers applied to test packets after the Fixed and Runtime Parameters are passed to that process.  The ICMP measurement process and protocol will dictate the format of sequence numbers and other Identifiers.

Refer to Section 4.4 of [RFC6673] for an expanded discussion of the instruction to "send a Type-P packet back to the Src as quickly as possible" in Section 2.6 of [RFC2681].  Section 8 of [RFC6673] presents additional requirements that MUST be included in the Method of Measurement for this metric.

9.3.2.  Packet Stream Generation

This section provides details regarding packet traffic, which is used as the basis for measurement.  In IPPM Metrics, this is called the "stream"; this stream can easily be described by providing the list of stream Parameters.

The ICMP metrics use a sending discipline called "SendOnRcv" or Send On Receive.  This is a modification of Section 3 of [RFC3432], which prescribes the method for generating Periodic streams using associated Parameters as defined below for this description:

incT:  The nominal duration of the inter-packet interval, first bit
   to first bit.

dT:  The duration of the interval for allowed sample start times.

The incT stream Parameter will be specified as a Runtime Parameter,
and dT is not used in SendOnRcv.

A SendOnRcv sender behaves exactly like a Periodic stream generator
while all reply packets arrive with RTD < incT, and the inter-packet
interval will be constant.

If a reply packet arrives with RTD >= incT, then the inter-packet
interval for the next sending time is nominally RTD.

If a reply packet fails to arrive within Tmax, then the inter-packet
interval for the next sending time is nominally Tmax.

If an immediate Send On Reply arrival is desired, then set incT = 0.

## 9.3.3.  Traffic Filtering (Observation) Details

N/A

## 9.3.4.  Sampling Distribution

N/A

## 9.3.5.  Runtime Parameters and Data Format

Runtime Parameters are input factors that must be determined,
configured into the measurement system, and reported with the results
for the context to be complete.

Src:  The IP address of the host in the Src Role (format
   ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
   for IPv6; see Section 4 of [RFC6991]).

Dst:  The IP address of the host in the Dst Role (format
   ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
   for IPv6; see Section 4 of [RFC6991]).

incT:  The nominal duration of the inter-packet interval, first bit
   to first bit, expressed in units of seconds, as a positive value
   of type decimal64 with fraction digits = 4 (see Section 9.3 of
   [RFC6020]) and with a resolution of 0.0001 seconds (0.1 ms).

T0:  A time, the start of a measurement interval (format "date-time"
   as specified in Section 5.6 of [RFC3339]; see also "date-and-time"
   in Section 3 of [RFC6991]).  The UTC Time Zone is required by
   Section 6.1 of [RFC2330].  When T0 is "all-zeros", a start time is

unspecified and Tf is to be interpreted as the duration of the
measurement interval.  The start time is controlled through other
means.

Count:  The total count of ICMP Echo Requests to send, formatted as a
   uint16, as per Section 9.2 of [RFC6020].

See the Packet Stream Generation section for additional Runtime
Parameters.

## 9.3.6.  Roles

Src:  Launches each packet and waits for return transmissions from
   the Dst.

Dst:  Waits for each packet from the Src and sends a return packet to
   the Src (ICMP Echo Reply, Type 0).

## 9.4.  Output

This category specifies all details of the output of measurements
using the metric.

## 9.4.1.  Type

Latency and Loss Types are discussed in the subsections below.

## 9.4.2.  Reference Definition

For all output types:

T0:  The start of a measurement interval (format "date-time" as
   specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
   Section 3 of [RFC6991]).  The UTC Time Zone is required by
   Section 6.1 of [RFC2330].

Tf:  The end of a measurement interval (format "date-time" as
   specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
   Section 3 of [RFC6991]).  The UTC Time Zone is required by
   Section 6.1 of [RFC2330].

TotalCount:  The count of packets actually sent by the Src to the Dst
   during the measurement interval.

For each <statistic> or Percent_LossRatio, one of the following
subsections applies.

## 9.4.2.1.  Mean

The mean SHALL be calculated using the conditional distribution of
all packets with a finite value of round-trip delay (undefined delays

are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

See Section 4.2.2 of [RFC6049] for details on calculating this
statistic; see also Section 4.2.3 of [RFC6049].

Mean:  The time value of the result is expressed in units of seconds,
   as a positive value of type decimal64 with fraction digits = 9
   (see Section 9.3 of [RFC6020]) with a resolution of
   0.000000001 seconds (1.0 ns), and with lossless conversion to/from
   the 64-bit NTP timestamp as per Section 6 of [RFC5905].

## 9.4.2.2.  Min

The minimum SHALL be calculated using the conditional distribution of
all packets with a finite value of round-trip delay (undefined delays
are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

See Section 4.3.2 of [RFC6049] for details on calculating this
statistic; see also Section 4.3.3 of [RFC6049].

Min:  The time value of the result is expressed in units of seconds,
   as a positive value of type decimal64 with fraction digits = 9
   (see Section 9.3 of [RFC6020]) with a resolution of
   0.000000001 seconds (1.0 ns), and with lossless conversion to/from
   the 64-bit NTP timestamp as per Section 6 of [RFC5905].

## 9.4.2.3.  Max

The maximum SHALL be calculated using the conditional distribution of
all packets with a finite value of round-trip delay (undefined delays
are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional
distribution to exclude undefined values of delay, and see Section 5
of [RFC6703] for background on this analysis choice.

See Section 4.3.2 of [RFC6049] for a closely related method for
calculating this statistic; see also Section 4.3.3 of [RFC6049].  The
formula is as follows:

   Max = (FiniteDelay[j])

   such that for some index, j, where 1 <= j <= N

FiniteDelay[j] >= FiniteDelay[n] for all n

   Max:  The time value of the result is expressed in units of seconds,
         as a positive value of type decimal64 with fraction digits = 9
         (see Section 9.3 of [RFC6020]) with a resolution of
         0.000000001 seconds (1.0 ns), and with lossless conversion to/from
         the 64-bit NTP timestamp as per Section 6 of [RFC5905].

## 9.4.2.4.  Percent_LossRatio

   For LossRatio, the count of lost packets to total packets sent is the
   basis for the loss ratio calculation as per Section 4.1 of [RFC7680].

   Percent_LossRatio:  The numeric value of the result is expressed in
         units of lost packets to total packets times 100%, as a positive
         value of type decimal64 with fraction digits = 9 (see Section 9.3
         of [RFC6020]) with a resolution of 0.0000000001.

## 9.4.3.  Metric Units

   The <statistic> of round-trip delay is expressed in seconds, where
   <statistic> is one of:

   *  Mean

   *  Min

   *  Max

   The round-trip loss ratio is expressed as a percentage of lost
   packets to total packets sent.

## 9.4.4.  Calibration

   Section 3.7.3 of [RFC7679] provides a means to quantify the
   systematic and random errors of a time measurement.  Calibration in-
   situ could be enabled with an internal loopback at the Source host
   that includes as much of the measurement system as possible, performs
   address manipulation as needed, and provides some form of isolation
   (e.g., deterministic delay) to avoid send-receive interface
   contention.  Some portion of the random and systematic error can be
   characterized in this way.

   When a measurement controller requests a calibration measurement, the
   loopback is applied and the result is output in the same format as a
   normal measurement, with an additional indication that it is a
   calibration result.

   Both internal loopback calibration and clock synchronization can be
   used to estimate the available accuracy of the Output Metric Units.
   For example, repeated loopback delay measurements will reveal the

portion of the output result resolution that is the result of system
noise and is thus inaccurate.

## 9.5.  Administrative Items

## 9.5.1.  Status

Current

## 9.5.2.  Requester

RFC 8912

## 9.5.3.  Revision

1.0

## 9.5.4.  Revision Date

2021-11-17

## 9.6.  Comments and Remarks

None

## 10.  TCP Round-Trip Delay and Loss Registry Entries

This section specifies four initial Registry Entries for the Passive
assessment of TCP Round-Trip Delay (RTD) and another entry for the
TCP Round-Trip Loss Count.

All column entries besides the ID, Name, Description, and Output
Reference Method categories are the same; thus, this section defines
four closely related Registry Entries.  As a result, IANA has
assigned corresponding URLs to each of the four Named Metrics.

## 10.1.  Summary

This category includes multiple indexes to the Registry Entries: the
element ID and Metric Name.

## 10.1.1.  ID (Identifier)

IANA has allocated the numeric Identifiers 22-26 for the five Named
Metric Entries in Section 10.  See Section 10.1.2 for mapping to
Names.

## 10.1.2.  Name

22:  RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Mean

```
   23:  RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Min

   24:  RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Max

   25:  RTDelay_Passive_IP-TCP-HS_RFC8912sec10_Seconds_Singleton
```

   Note that a midpoint observer only has the opportunity to compose a
   single RTDelay on the TCP handshake.

```
   26:  RTLoss_Passive_IP-TCP_RFC8912sec10_Packet_Count
```

10.1.3. URI

   URL: https://www.iana.org/assignments/performance-metrics/
   RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Mean

   URL: https://www.iana.org/assignments/performance-metrics/
   RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Min

   URL: https://www.iana.org/assignments/performance-metrics/
   RTDelay_Passive_IP-TCP_RFC8912sec10_Seconds_Max

   URL: https://www.iana.org/assignments/performance-metrics/
   RTDelay_Passive_IP-TCP-HS_RFC8912sec10_Seconds_Singleton

   URL: https://www.iana.org/assignments/performance-metrics/
   RTLoss_Passive_IP-TCP_RFC8912sec10_Packet_Count

10.1.4. Description

   RTDelay: This metric assesses the round-trip delay of TCP packets
      constituting a single connection, exchanged between two hosts. We
      consider the measurement of round-trip delay based on a single
      Observation Point (OP) [RFC7011] somewhere in the network. The
      output is the round-trip delay for all successfully exchanged
      packets expressed as the <statistic> of their conditional delay
      distribution, where <statistic> is one of:

      * Mean

      * Min

      * Max

   RTDelay Singleton: This metric assesses the round-trip delay of TCP
      packets initiating a single connection (or 3-way handshake),
      exchanged between two hosts. We consider the measurement of
      round-trip delay based on a single Observation Point (OP)
      [RFC7011] somewhere in the network. The output is the single
      measurement of Round-trip delay, or Singleton.

RTLoss: This metric assesses the estimated loss count for TCP
   packets constituting a single connection, exchanged between two
   hosts. We consider the measurement of round-trip delay based on a
   single OP [RFC7011] somewhere in the network. The output is the
   estimated loss count for the measurement interval.

10.1.5. Change Controller

   IETF

10.1.6. Version (of Registry Format)

   1.0

10.2. Metric Definition

   This category includes columns to prompt the entry of all necessary
   details related to the metric definition, including the RFC reference
   and values of input factors, called "Fixed Parameters".

10.2.1. Reference Definition

   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>. [RFC2681]

   Although there is no RFC that describes Passive Measurement of round-
   trip delay, the parallel definition for Active Measurement is
   provided in [RFC2681].

   This metric definition uses the term "wire time" as defined in
   Section 10.2 of [RFC2330], and the terms "singleton" and "sample" as
   defined in Section 11 of [RFC2330]. (Section 2.4 of [RFC2681]
   provides the reference definition of the singleton (single value)
   round-trip delay metric. Section 3.4 of [RFC2681] provides the
   reference definition expanded to cover a multi-singleton sample.)

   With the OP [RFC7011] typically located between the hosts
   participating in the TCP connection, the round-trip delay metric
   requires two individual measurements between the OP and each host,
   such that the Spatial Composition [RFC6049] of the measurements
   yields a round-trip delay singleton (we are extending the composition
   of one-way subpath delays to subpath round-trip delay).

   Using the direction of TCP SYN transmission to anchor the
   nomenclature, host A sends the SYN, and host B replies with SYN-ACK
   during connection establishment. The direction of SYN transfer is
   considered the Forward direction of transmission, from A through the
   OP to B (the Reverse direction is B through the OP to A).

   Traffic Filters reduce the packet streams at the OP to a Qualified

bidirectional flow of packets.

In the definitions below, Corresponding Packets are transferred in
different directions and convey a common value in a TCP header field
that establishes correspondence (to the extent possible). Examples
may be found in the TCP timestamp fields.

For a real number, RTD_fwd, >> the round-trip delay in the Forward
direction from the OP to host B at time T' is RTD_fwd << it is
REQUIRED that the OP observed a Qualified Packet to host B at wire
time T', that host B received that packet and sent a Corresponding
Packet back to host A, and the OP observed the Corresponding Packet
at wire time T' + RTD_fwd.

For a real number, RTD_rev, >> the round-trip delay in the Reverse
direction from the OP to host A at time T'' is RTD_rev << it is
REQUIRED that the OP observed a Qualified Packet to host A at wire
time T'', that host A received that packet and sent a Corresponding
Packet back to host B, and that the OP observed the Corresponding
Packet at wire time T'' + RTD_rev.

Ideally, the packet sent from host B to host A in both definitions
above SHOULD be the same packet (or, when measuring RTD_rev first,
the packet from host A to host B in both definitions should be the
same).

The REQUIRED Composition Function for a singleton of round-trip delay
at time T (where T is the earliest of T' and T'' above) is:

RTDelay = RTD_fwd + RTD_rev

Note that when the OP is located at host A or host B, one of the
terms composing RTDelay will be zero or negligible.

Using the abbreviation HS to refer to the TCP handshake: when the
Qualified and Corresponding Packets are a TCP-SYN and a TCP-SYN-ACK,
RTD_fwd == RTD_HS_fwd.

When the Qualified and Corresponding Packets are a TCP-SYN-ACK and a
TCP-ACK, RTD_rev == RTD_HS_rev.

The REQUIRED Composition Function for a singleton of round-trip delay
for the connection handshake is:

RTDelay_HS = RTD_HS_fwd + RTD_HS_rev

The definition of round-trip loss count uses the nomenclature
developed above, based on observation of the TCP header sequence
numbers and storing the sequence number gaps observed. Packet losses
can be inferred from:

Out-of-order segments: TCP segments are transmitted with
   monotonically increasing sequence numbers, but these segments may
   be received out of order. Section 3 of [RFC4737] describes the
   notion of "next expected" sequence numbers, which can be adapted
   to TCP segments (for the purpose of detecting reordered packets).
   Observation of out-of-order segments indicates loss on the path
   prior to the OP and creates a gap.

Duplicate segments: Section 2 of [RFC5560] defines identical packets
   and is suitable for evaluation of TCP packets to detect
   duplication. Observation of a segment duplicates a segment
   previously observed (and thus no corresponding observed segment
   gap) indicates loss on the path following the OP (e.g., the
   segment overlaps part of the octet stream already observed at the
   OP).

Each observation of an out-of-order or duplicate segment infers a
singleton of loss, but the composition of round-trip loss counts will
be conducted over a measurement interval that is synonymous with a
single TCP connection.

With the above observations in the Forward direction over a
measurement interval, the count of out-of-order and duplicate
segments is defined as RTL_fwd. Comparable observations in the
Reverse direction are defined as RTL_rev.

For a measurement interval (corresponding to a single TCP connection)
T0 to Tf, the REQUIRED Composition Function for the two single-
direction counts of inferred loss is:

RTLoss = RTL_fwd + RTL_rev

10.2.2. Fixed Parameters

Traffic Filters:
   IPv4 header values:
      DSCP: Set to 0
      Protocol: Set to 06 (TCP)

   IPv6 header values:
      DSCP: Set to 0
      Hop Count: Set to 255
      Next Header: Set to 6 (TCP)
      Flow Label: Set to 0
      Extension Headers: None

   TCP header values:
      Flags: ACK, SYN, FIN, set as required
      Timestamps Option (TSopt): Set. See Section 3.2 of [RFC7323]

10.3. Method of Measurement

This category includes columns for references to relevant sections of the RFC(s) and any supplemental information needed to ensure an unambiguous method for implementations.

10.3.1. Reference Methods

The foundational methodology for this metric is defined in Section 4 of [RFC7323] using the Timestamps option with modifications that allow application at a mid-path OP [RFC7011]. Further details and applicable heuristics were derived from [Strowes] and [Trammell-14].

The Traffic Filter at the OP is configured to observe a single TCP connection. When the SYN/SYN-ACK/ACK handshake occurs, it offers the first opportunity to measure both RTD_fwd (on the SYN to SYN-ACK pair) and RTD_rev (on the SYN-ACK to ACK pair). Label this singleton of RTDelay as RTDelay_HS (composed using the Forward and Reverse measurement pair). RTDelay_HS SHALL be treated separately from other RTDelays on data-bearing packets and their ACKs. The RTDelay_HS value MAY be used as a consistency check on the composed values of RTDelay for payload-bearing packets.

For payload-bearing packets, the OP measures the time interval between observation of a packet with sequence number "s" and the corresponding ACK with the same sequence number. When the payload is transferred from host A to host B, the observed interval is RTD_fwd.

For payload-bearing packets, each observation of an out-of-order or duplicate segment infers a loss count, but the composition of round-trip loss counts will be conducted over a measurement interval that is synonymous with a single TCP connection.

Because many data transfers are unidirectional (say, in the Forward direction from host A to host B), it is necessary to use pure ACK packets with Timestamp (TSval) and packets with the Timestamp value echo to perform a RTD_rev measurement. The time interval between observation of the ACK from B to A, and the Corresponding Packet with a Timestamp Echo Reply (TSecr) field [RFC7323], is the RTD_rev.

Delay Measurement Filtering Heuristics:

* If data payloads were transferred in both Forward and Reverse directions, then the Round-Trip Time Measurement rule in Section 4.1 of [RFC7323] could be applied. This rule essentially excludes any measurement using a packet unless it makes progress in the transfer (advances the left edge of the send window, consistent with [Strowes]).

* A different heuristic from [Trammell-14] is to exclude any RTD_rev that is larger than previously observed values. This would tend to exclude Reverse measurements taken when the application has no

data ready to send, because considerable time could be added to RTD_rev from this source of error.

* Note that the above heuristic assumes that host A is sending data. Host A expecting a download would mean that this heuristic should be applied to RTD_fwd.

* The statistic calculations to summarize the delay (RTDelay) SHALL be performed on the conditional distribution, conditioned on successful Forward and Reverse measurements that follow the heuristics.

Method for Inferring Loss:

* The OP tracks sequence numbers and stores gaps for each direction of transmission, as well as the next expected sequence number as discussed in [Trammell-14] and [RFC4737]. Loss is inferred from out-of-order segments and duplicate segments.

Loss Measurement Filtering Heuristics:

* [Trammell-14] adds a window of evaluation based on the RTDelay.

* Distinguish reordered packets from out-of-order segments due to loss, because the sequence number gap is filled during the same RTDelay window. Segments detected as reordered according to [RFC4737] MUST reduce the loss count inferred from out-of-order segments.

* Spurious (unneeded) retransmissions (observed as duplicates) can also be reduced in this way, as described in [Trammell-14].

Sources of Error:

* The principal source of RTDelay error is the host processing time to return a packet that defines the termination of a time interval. The heuristics above intend to mitigate these errors by excluding measurements where host processing time is a significant part of RTD_fwd or RTD_rev.

* A key source of RTLoss error is observation loss, as described in Section 3 of [Trammell-14].

10.3.2. Packet Stream Generation

N/A

10.3.3. Traffic Filtering (Observation) Details

The Fixed Parameters above give a portion of the Traffic Filter. Other aspects will be supplied as Runtime Parameters (below).

. Sampling Distribution

   This metric requires a complete sample of all packets that qualify
   according to the Traffic Filter criteria.

10.3.5. Runtime Parameters and Data Format

   Runtime Parameters are input factors that must be determined,
   configured into the measurement system, and reported with the results
   for the context to be complete.

   Src: The IP address of the host in the host A Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see Section 4 of [RFC6991]).

   Dst: The IP address of the host in the host B Role (format
      ipv4-address-no-zone value for IPv4 or ipv6-address-no-zone value
      for IPv6; see Section 4 of [RFC6991]).

   T0: A time, the start of a measurement interval (format "date-time"
      as specified in Section 5.6 of [RFC3339]; see also "date-and-time"
      in Section 3 of [RFC6991]). The UTC Time Zone is required by
      Section 6.1 of [RFC2330]. When T0 is "all-zeros", a start time is
      unspecified and Tf is to be interpreted as the duration of the
      measurement interval. The start time is controlled through other
      means.

   Tf: Optionally, the end of a measurement interval (format
      "date-time" as specified in Section 5.6 of [RFC3339]; see also
      "date-and-time" in Section 3 of [RFC6991]), or the duration (see
      T0). The UTC Time Zone is required by Section 6.1 of [RFC2330].
      Alternatively, the end of the measurement interval MAY be
      controlled by the measured connection, where the second pair of
      FIN and ACK packets exchanged between host A and host B
      effectively ends the interval.

   TTL or Hop Limit: Set at desired value.

10.3.6. Roles

   host A: Launches the SYN packet to open the connection. The Role of
      "host A" is synonymous with the IP address used at host A.

   host B: Replies with the SYN-ACK packet to open the connection. The
      Role of "host B" is synonymous with the IP address used at host B.

10.4. Output

   This category specifies all details of the output of measurements
   using the metric.

. Type

   RTDelay Types are discussed in the subsections below.

   For RTLoss: The count of lost packets.

. Reference Definition

   For all output types:

   T0: The start of a measurement interval (format "date-time" as
      specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
      Section 3 of [RFC6991]). The UTC Time Zone is required by
      Section 6.1 of [RFC2330].

   Tf: The end of a measurement interval (format "date-time" as
      specified in Section 5.6 of [RFC3339]; see also "date-and-time" in
      Section 3 of [RFC6991]). The UTC Time Zone is required by
      Section 6.1 of [RFC2330]. The end of the measurement interval MAY
      be controlled by the measured connection, where the second pair of
      FIN and ACK packets exchanged between host A and host B
      effectively ends the interval.

   RTDelay_Passive_IP-TCP-HS: The round-trip delay of the handshake is
      a Singleton.

   RTLoss: The count of lost packets.

   For each <statistic>, Singleton, or Loss Count, one of the following
   subsections applies.

. Mean

   The mean SHALL be calculated using the conditional distribution of
   all packets with a finite value of round-trip delay (undefined delays
   are excluded) -- a single value, as follows:

   See Section 4.1 of [RFC3393] for details on the conditional
   distribution to exclude undefined values of delay, and see Section 5
   of [RFC6703] for background on this analysis choice.

   See Section 4.2.2 of [RFC6049] for details on calculating this
   statistic; see also Section 4.2.3 of [RFC6049].

   Mean: The time value of the result is expressed in units of seconds,
      as a positive value of type decimal64 with fraction digits = 9
      (see Section 9.3 of [RFC6020]) with a resolution of
      0.000000001 seconds (1.0 ns), and with lossless conversion to/from
      the 64-bit NTP timestamp as per Section 6 of [RFC5905].

10.4.2.2. Min

The minimum SHALL be calculated using the conditional distribution of all packets with a finite value of round-trip delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.3.2 of [RFC6049] for details on calculating this statistic; see also Section 4.3.3 of [RFC6049].

Min: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

10.4.2.3. Max

The maximum SHALL be calculated using the conditional distribution of all packets with a finite value of round-trip delay (undefined delays are excluded) -- a single value, as follows:

See Section 4.1 of [RFC3393] for details on the conditional distribution to exclude undefined values of delay, and see Section 5 of [RFC6703] for background on this analysis choice.

See Section 4.3.2 of [RFC6049] for a closely related method for calculating this statistic; see also Section 4.3.3 of [RFC6049]. The formula is as follows:

```
Max = (FiniteDelay[j])

such that for some index, j, where 1 <= j <= N
FiniteDelay[j] >= FiniteDelay[n] for all n
```

Max: The time value of the result is expressed in units of seconds, as a positive value of type decimal64 with fraction digits = 9 (see Section 9.3 of [RFC6020]) with a resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per Section 6 of [RFC5905].

10.4.2.4. Singleton

The singleton SHALL be calculated using the successful RTD_fwd (on the SYN to SYN-ACK pair) and RTD_rev (on the SYN-ACK to ACK pair), see Section 10.3.1.

The singleton time value of the result is expressed in units of

seconds, as a positive value of type decimal64 with fraction digits = 9 (see [Section 9.3 of [RFC6020]](#)) with resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [Section 6 of [RFC5905]](#).

10.4.2.5. Loss Counts

RTLoss_Passive_IP-TCP_RFC8912sec10_Packet_Count: The count of lost packets.

Observation of an out-of-order segment or duplicate segment infers a loss count, after application of the Definitions of [Section 10.2.1](#) and the Loss Measurement Filtering Heuristics of [Section 10.3.1](#). The composition of round-trip loss counts will be conducted over a measurement interval that is synonymous with a single TCP connection.

For a measurement interval (corresponding to a single TCP connection) T0 to Tf, the REQUIRED Composition Function for the two single-direction counts of inferred loss is:

RTLoss = RTL_fwd + RTL_rev

Packet count: The numeric value of the result is expressed in units of lost packets, as a positive value of type uint64 (represents integer values between 0 and 18446744073709551615, inclusively (see [Section 9.2 of [RFC6020]](#)).

10.4.3. Metric Units

The <statistic> of round-trip delay is expressed in seconds, where <statistic> is one of:

* Mean

* Min

* Max

The round-trip delay of the TCP handshake singleton is expressed in seconds.

The round-trip loss count is expressed as a number of packets.

10.4.4. Calibration

Passive Measurements at an OP could be calibrated against an Active Measurement (with loss emulation) at host A or host B, where the Active Measurement represents the ground truth.

10.5. Administrative Items

10.5.1. Status

   Current

10.5.2. Requester

   [RFC 8912](#)

10.5.3. Revision

   1.0

10.5.4. Revision Date

   2021-11-17

10.6. Comments and Remarks

   None

11. Security Considerations

   These Registry Entries represent no known implications for Internet
   security. With the exception of [RFC1035], each RFC referenced above
   contains a Security Considerations section. Further, the Large-scale
   Measurement of Broadband Performance (LMAP) framework [RFC7594]
   provides both security and privacy considerations for measurements.

   There are potential privacy considerations for observed traffic,
   particularly for Passive Metrics as discussed in [Section 10](#). An
   attacker that knows that its TCP connection is being measured can
   modify its behavior to skew the measurement results.

12. IANA Considerations

   IANA has populated the Performance Metrics Registry defined in
   [RFC8911] with the values defined in Sections [4](#) through [10](#).

   See the IANA Considerations section of [RFC8911] for additional
   considerations.

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Acknowledgments

answering questions related to the presentation of the Registry and accessibility of the complete template via URL.

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