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**Initial Performance Metrics Registry Entries
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Abstract

This memo defines the set of Initial Entries for the IANA Performance Metrics Registry. 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 Latency and Loss.

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.

Status of This Memo

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[1](#). Introduction

This memo proposes an initial set of entries for the Performance Metrics Registry. It uses terms and definitions from the 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 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 which need to be registered, it became clear that none of the existing metric templates fully satisfies the particular needs of a registry.

Therefore, [[I-D.ietf-ippm-metric-registry](#)] defines the overall format

for a Performance Metrics Registry. Section 5 of [[I-D.ietf-ippm-metric-registry](#)] also gives guidelines for those requesting registration of a Metric, that is the creation of entry(s)

in the Performance Metrics Registry: "In essence, there needs to be evidence that a candidate Registered Performance Metric has significant industry interest, or has seen deployment, and there is agreement that the candidate Registered Performance Metric serves its

intended purpose." The process in [[I-D.ietf-ippm-metric-registry](#)] also requires that new entries are administered by IANA through Specification Required policy, which includes Expert Review, which will ensure that the metrics are tightly defined.

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 [[I-D.ietf-ippm-metric-registry](#)].

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.

Legend:

Registry Categories and Columns, shown as

Category

Column Column

Summary

Identifier Name URIs Desc. Reference Change Controller Ver

Metric Definition

Reference Definition Fixed Parameters

Method of Measurement

Reference Packet Traffic Sampling Run-time 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 the UDP Round-trip Latency, and another entry for 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. 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 beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes

two closely-related registry entries. As a result, IANA is also asked to assign a corresponding URL to each Named Metric.

4.1. Summary

This category includes multiple indexes to the registry entry: the element ID and metric name.

4.1.1. ID (Identifier)

IANA is asked to assign different numeric identifiers to each of the two Named Metrics.

4.1.2. Name

RTDelay_Active_IP-UDP-Periodic_RFCXXXXsec4_Seconds_95Percentile

RTLoss_Active_IP-UDP-Periodic_RFCXXXXsec4_Percent_LossRatio

4.1.3. URIs

URL: <https://www.iana.org/> ... <name>

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), and 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), and the Output is the Round-trip loss ratio for all successfully exchanged 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

Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip Delay Metric for IPPM", [RFC 2681](#), September 1999.

[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 [\[RFC2681\]](#) definition of "Round-trip-Delay between Src and Dst" 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 "Dst", and ultimately receive the corresponding return packet from "Dst" (when neither are 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 re-used in other IPPM literature to refer to different quantities, and cannot be used as a global variable name.

Morton, A., "Round-trip Packet Loss Metrics", [RFC 6673](#), August 2012.

[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 \[RFC2330\]](#):

- o IPv4 header values:
 - * DSCP: set to 0

- * TTL: set to 255
- * Protocol: set to 17 (UDP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 17 (UDP)
 - * Flow Label: set to zero
 - * Extension Headers: none
- o UDP header values:
 - * Checksum: the checksum MUST be calculated and the non-zero checksum included in the header
- o UDP Payload
 - * total of 100 bytes

Other measurement parameters:

- o Tmax: a loss threshold waiting time
 - * 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 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 unambiguous methods for implementations.

4.3.1. Reference Method

The methodology for this metric is defined as Type-P-Round-trip-Delay-Poisson-Stream in [section 2.6 of RFC 2681 \[RFC2681\]](#) and [section 3.6 of RFC 2681 \[RFC2681\]](#) using the Type-P and Tmax defined under Fixed Parameters. 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.

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 which 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 [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 time-stamps, if they are conveyed in the packet payload.

Refer to [Section 4.4 of \[RFC6673\]](#) for expanded discussion of the instruction to "send a Type-P packet back to the Src as quickly as possible" in [Section 2.6 of RFC 2681 \[RFC2681\]](#). [Section 8 of \[RFC6673\]](#) presents additional requirements which MUST be included in the method of measurement for this metric.

4.3.2. Packet Stream Generation

This section gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and 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 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 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 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 therefore 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](#)

NA

[4.3.4. Sampling Distribution](#)

NA

[4.3.5. Run-time Parameters and Data Format](#)

Run-time 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time")

as specified in [Section 5.6 of \[RFC3339\]](#), see also [Section 3](#) of

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[RFC6991]). The UTC Time Zone is required by [Section 6.1 of RFC2330](#). When T0 is "all-zeros", a end time 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 Dst.

Dst waits for each packet from Src and sends a return packet to 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), 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 [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), $F(95\text{Percentile}) \geq 95\%$ 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.

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-and-time" as specified in [Section 5.6 of RFC3339](#), see also [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-and-time" as specified in [Section 5.6 of RFC3339](#), see also [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 Dst during the measurement interval.

For

RTDelay_Active_IP-UDP-Periodic_RFCXXXXsec4_Seconds_95Percentile:

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 resolution of 0.000000001 seconds (1.0 ns).

For

RTLoss_Active_IP-UDP-Periodic_RFCXXXXsec4_Percent_LossRatio:

Percentile 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 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. In-situ calibration 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 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 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 which is the result of system noise, and thus inaccurate.

4.5. Administrative items

4.5.1. Status

Current

4.5.2. Requester

This RFC number

4.5.3. Revision

1.0

4.5.4. Revision Date

YYYY-MM-DD

4.6. Comments and Remarks

None.

5. Packet Delay Variation Registry Entry

This section gives an initial registry entry for a Packet Delay Variation metric.

5.1. Summary

This category includes multiple indexes to the registry entries, the element ID and metric name.

5.1.1. ID (Identifier)

<insert numeric identifier, an integer>

5.1.2. Name

OWPDV_Active_IP-UDP-Periodic_RFCXXXXsec5_Seconds_95Percentile

5.1.3. URIs

URL: <https://www.iana.org/> ... <name>

5.1.4. Description

An assessment of packet delay variation with respect to the minimum delay observed on the periodic stream, and the Output is expressed as the 95th percentile of the 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](#), May 1998. [[RFC2330](#)]

Demichelis, C. and P. Chimento, "IP Packet Delay Variation Metric for IP Performance Metrics (IPPM)", [RFC 3393](#), November 2002. [[RFC3393](#)]

Morton, A. and B. Claise, "Packet Delay Variation Applicability Statement", [RFC 5481](#), March 2009. [[RFC5481](#)]

Mills, D., Martin, J., Burbank, J., and W. Kasch, "Network Time Protocol Version 4: Protocol and Algorithms Specification", [RFC 5905](#), June 2010. [[RFC5905](#)]

See sections [2.4](#) and [3.4](#) of [[RFC3393](#)]. Singleton delay differences measured 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)".

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5.2.2. Fixed Parameters

- o IPv4 header values:
 - * DSCP: set to 0
 - * TTL: set to 255
 - * Protocol: set to 17 (UDP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 17 (UDP)
 - * Flow Label: set to zero
 - * Extension Headers: none
- o UDP header values:
 - * Checksum: the checksum MUST be calculated and the non-zero checksum included in the header
- o 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 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 category 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 unambiguous methods for implementations.

5.3.1. Reference Method

See [section 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 which 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 [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 time-stamps, if they are conveyed in the packet payload.

5.3.2. Packet Stream Generation

This section gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and 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 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 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 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 therefore 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](#)

NA

[5.3.4. Sampling Distribution](#)

NA

[5.3.5. Run-time 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time"

as specified in [Section 5.6 of \[RFC3339\]](#), see also [Section 3 of \[RFC6991\]](#)). The UTC Time Zone is required by [Section 6.1 of \[RFC2330\]](#). When T0 is "all-zeros", a end time 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 Dst.

Dst waits for each packet from Src and sends a return packet to Src.

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), 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 [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), $F(95\text{Percentile}) \geq 95\%$ 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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. In-situ calibration 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 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 additional indication that it is a calibration result. In any measurement, the measurement function SHOULD report its current estimate of 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 which is the result of

system
noise, and thus inaccurate.

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5.5. Administrative items

5.5.1. Status

Current

5.5.2. Requester

This RFC number

5.5.3. Revision

1.0

5.5.4. Revision Date

YYYY-MM-DD

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.

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 using different names. [RFC 2681](#) [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.

Note to IANA: Each Registry "Name" below specifies a single registry entry, whose output format varies in accordance with the name.

All column entries beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes two closely-related registry entries. As a result, IANA is also asked to assign corresponding URLs to each Named Metric.

6.1. Summary

This category includes multiple indexes to the registry entries, the element ID and metric name.

6.1.1. ID (Identifier)

<insert numeric identifier, an integer>

IANA is asked to assign different numeric identifiers to each of the two Named Metrics.

6.1.2. Name

RTDNS_Active_IP-UDP-Poisson_RFCXXXXsec6_Seconds_Raw

RLDNS_Active_IP-UDP-Poisson_RFCXXXXsec6_Logical_Raw

6.1.3. URI

URL: <https://www.iana.org/> ... <name>

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

Mockapetris, P., "Domain names - implementation and specification", STD 13, [RFC 1035](#), November 1987. (and updates)

[RFC1035]

Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip Delay Metric for IPPM", [RFC 2681](#), September 1999.

[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 [\[RFC2681\]](#) definition of "Round-trip-Delay between Src and Dst at T" 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 "Dst", and ultimately receive the corresponding return packet from "Dst" (when neither are lost).

Morton, A., "Round-trip Packet Loss Metrics", [RFC 6673](#), August 2012.

[RFC6673]

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 \[RFC2330\]](#):

- o IPv4 header values:
 - * DSCP: set to 0
 - * TTL set to 255
 - * Protocol: set to 17 (UDP)
- o IPv6 header values:

- * DSCP: set to 0
- * Hop Count: set to 255
- * Next Header: set to 17 (UDP)
- * Flow Label: set to zero
- * Extension Headers: none
- o UDP header values:
 - * Source port: 53
 - * Destination port: 53
 - * Checksum: the checksum must be calculated and the non-zero checksum included in the header
- o Payload: The payload contains a DNS message as defined in [RFC 1035](#) [[RFC1035](#)] with the following values:
 - * The DNS header section contains:
 - + Identification (see the Run-time column)
 - + QR: set to 0 (Query)
 - + OPCODE: set to 0 (standard query)
 - + AA: not set
 - + TC: not set
 - + RD: set to one (recursion desired)
 - + RA: not set
 - + RCODE: not set
 - + QDCOUNT: set to one (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 Run-time column
 - + QTYPE: the query type provided as input for the test, see the Run-time column
 - + QCLASS: set to 1 for IN
- * The other sections do not contain any Resource Records.

Other measurement parameters:

- o Tmax: a loss threshold waiting time (and to help disambiguate queries)
 - * 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 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 unambiguous methods for implementations.

6.3.1. Reference Method

The methodology for this metric is defined as Type-P-Round-trip-Delay-Poisson-Stream in [section 2.6 of RFC 2681 \[RFC2681\]](#) and [section 3.6 of RFC 2681 \[RFC2681\]](#) using the Type-P and Timeout defined under Fixed Parameters.

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 T_{max} . Also, when all packet delays are stored, the process

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which 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 [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 expanded discussion of the instruction to "send a Type-P packet back to the Src as quickly as possible" in [Section 2.6 of RFC 2681 \[RFC2681\]](#). 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 which 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 gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and can easily be described by providing the list of stream parameters.

[Section 11.1.3 of RFC 2681 \[RFC2330\]](#) provides three methods to generate Poisson sampling intervals. The reciprocal of lambda is the average packet rate, thus the Run-time Parameter is `Reciprocal_lambda = 1/lambda`, in packets per second.

Method 3 is used, where given a start time (Run-time Parameter), the subsequent send times are all computed prior to measurement by computing the pseudo-random distribution of inter-packet send times, (truncating the distribution as specified in the Run-time Parameters), 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](#)

NA

[6.3.4. Sampling Distribution](#)

NA

[6.3.5. Run-time Parameters and Data Format](#)

Run-time 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-

time"

as specified in [Section 5.6 of \[RFC3339\]](#), see also [Section 3 of \[RFC6991\]](#)). The UTC Time Zone is required by [Section 6.1](#) of

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[[RFC2330](#)]. When T0 is "all-zeros", a end time 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 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 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, and which 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-up replies to 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 Dst.

Dst waits for each packet from Src and sends a return packet to 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#). This value is undefined when the response packet is not received at Src within waiting time 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.

6.4.3. Metric Units

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

RTLDNS: 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. In-situ calibration 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 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 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 which is the result of system noise, and thus inaccurate.

6.5. Administrative items

6.5.1. Status

Current

6.5.2. Requester

This RFC number

6.5.3. Revision

1.0

6.5.4. Revision Date

YYYY-MM-DD

6.6. Comments and Remarks

None

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

This section specifies five initial registry entries for the UDP Poisson One-way Delay, and one for UDP Poisson One-way Loss.

IANA Note: Registry "Name" below specifies multiple registry entries, whose output format varies according to the <statistic> element of the name that specifies one form of statistical summary. There is an additional metric name for the Loss metric.

All column entries beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes six closely-related registry entries. As a result, IANA is also asked to assign corresponding URLs to each Named Metric.

7.1. Summary

This category includes multiple indexes to the registry entries, the element ID and metric name.

7.1.1. ID (Identifier)

IANA is asked to assign different numeric identifiers to each of the six Metrics.

7.1.2. Name

OWDelay_Active_IP-UDP-Poisson-
Payload250B_RFCXXXsec7_Seconds_<statistic>

where <statistic> is one of:

- o 95Percentile
- o Mean
- o Min
- o Max
- o StdDev

OWLoss_Active_IP-UDP-Poisson-
Payload250B_RFCXXXsec7_Percent_LossRatio

7.1.3. URI and URL

URL: <https://www.iana.org/> ... <name>

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> One-way delay for all successfully exchanged packets based on their conditional delay distribution.

where <statistic> is one of:

- o 95Percentile
- o Mean
- o Min
- o Max
- o StdDev

OWLoss: This metric assesses the loss ratio of a stream of packets exchanged between two hosts (which are the two measurement points), and the Output is the One-way loss ratio for all successfully received packets expressed as a percentage.

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, <<http://www.rfc-editor.org/info/rfc7679>>.

[RFC7679]

Morton, A., and Stephan, E., "Spatial Composition of Metrics", [RFC 6049](#), January 2011.

[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., Kalidini, S., Zekauskas, M., and A. Morton, Ed., "A One-Way Loss Metric for IP Performance Metrics (IPPM)", [RFC 7680](#), DOI 10.17487/RFC7680, January 2016, <<http://www.rfc-editor.org/info/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:

- o IPv4 header values:
 - * DSCP: set to 0
 - * TTL: set to 255
 - * Protocol: Set to 17 (UDP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 17 (UDP)
 - * Flow Label: set to zero
 - * Extension Headers: none
- o UDP header values:
 - * Checksum: the checksum MUST be calculated and the non-zero checksum included in the header
- o 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 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 category 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 unambiguous methods for implementations.

7.3.1. Reference Method

The methodology for this metric is defined as Type-P-One-way-Delay-Poisson-Stream in [section 3.6 of \[RFC7679\]](#) and [section 4.6 of \[RFC7679\]](#) using the Type-P and Tmax defined under Fixed Parameters.

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 which 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 [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 [\[RFC5357\]](#), 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 measurement protocol dictates the format of sequence numbers and time-stamps conveyed in the TWAMP-Test packet payload.

7.3.2. Packet Stream Generation

This section gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and can easily be described by providing the list of stream parameters.

[Section 11.1.3 of RFC 2681 \[RFC2330\]](#) provides three methods to generate Poisson sampling intervals. The reciprocal of lambda is the

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average packet rate, thus the Run-time Parameter is
Reciprocal_lambda
= 1/lambda, in packets per second.

Method 3 SHALL be used, where given a start time (Run-time Parameter), the subsequent send times are all computed prior to measurement by computing the pseudo-random 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 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 packet per 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 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

NA

[7.3.4.](#) Sampling Distribution

NA

[7.3.5.](#) Run-time Parameters and Data Format

Run-time 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [Section 3 of \[RFC6991\]](#)). The UTC Time Zone is required by [Section 6.1 of \[RFC2330\]](#). When T0 is "all-zeros", a end time 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 Dst. This is the TWAMP Session-Sender.

Dst waits for each packet from Src and sends a return packet to Src. This 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

See subsection titles below for Types.

[7.4.2.](#) Reference Definition

For all output types ---

T0 the start of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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>, one of the following sub-sections apply:

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 [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), $F(95\text{Percentile}) \geq 95\%$ 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.2.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001

seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.3.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [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, and 4.3.3 of [\[RFC6049\]](#). The formula is as follows:

$$\text{Max} = (\text{FiniteDelay}[j])$$

such that for some index, j , where $1 \leq j \leq N$
 $\text{FiniteDelay}[j] \geq \text{FiniteDelay}[n]$ 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

7.4.2.5. Std_Dev

The 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 [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 standard deviation of a population.

Define Population Std_Dev_Delay as follows:
(where all packets n = 1 through N have a value for Delay[n], and MeanDelay calculated as in 7.4.2.2), and SQRT[] is the Square Root function:

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

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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

7.4.3. Metric Units

The <statistic> of One-way Delay is expressed in seconds.

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. In-situ calibration 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 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [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 additional indication that it is a calibration result. In any measurement, the measurement function SHOULD report its current estimate of 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 which is the result of system noise, and thus inaccurate.

[7.5.](#) Administrative items

[7.5.1.](#) Status

Current

[7.5.2.](#) Requester

This RFC number

[7.5.3.](#) Revision

1.0

7.5.4. Revision Date

YYYY-MM-DD

7.6. Comments and Remarks

None

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

This section specifies five initial registry entries for the UDP Periodic One-way Delay, and one for UDP Periodic One-way Loss.

IANA Note: Registry "Name" below specifies multiple registry entries, whose output format varies according to the <statistic> element of the name that specifies one form of statistical summary. There is an additional metric name for the Loss metric.

All column entries beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes six closely-related registry entries. As a result, IANA is also asked to assign corresponding URLs to each Named Metric.

8.1. Summary

This category includes multiple indexes to the registry entries, the element ID and metric name.

8.1.1. ID (Identifier)

IANA is asked to assign a different numeric identifiers to each of the six Metrics.

8.1.2. Name

OWDelay_Active_IP-UDP-Periodic20m-
Payload142B_RFCXXXXsec8_Seconds_<statistic>

where <statistic> is one of:

- o 95Percentile
- o Mean
- o Min
- o Max

- o StdDev

OWLoss_Active_IP-UDP-Periodic-
Payload142B_RFCXXXXsec8_Percent_LossRatio

8.1.3. URIs

URL: <https://www.iana.org/> ... <name>

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> One-way delay for all successfully exchanged packets based on their conditional delay distribution.

where <statistic> is one of:

- o 95Percentile
- o Mean
- o Min
- o Max
- o StdDev

OWLoss: This metric assesses the loss ratio of a stream of packets exchanged between two hosts (which are the two measurement points), and the Output is the One-way loss ratio for all successfully received packets expressed as a percentage.

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](https://www.rfc-editor.org/info/rfc7679), DOI 10.17487/RFC7679, January 2016, <<http://www.rfc-editor.org/info/rfc7679>>.

[RFC7679]

Morton, A., and Stephan, E., "Spatial Composition of Metrics", [RFC 6049](#), January 2011.

[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., Kalidini, S., Zekauskas, M., and A. Morton, Ed., "A One-Way Loss Metric for IP Performance Metrics (IPPM)", [RFC 7680](#), DOI 10.17487/RFC7680, January 2016, <<http://www.rfc-editor.org/info/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:

- o IPv4 header values:
 - * DSCP: set to 0
 - * TTL: set to 255
 - * Protocol: Set to 17 (UDP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 17 (UDP)

- * Flow Label: set to zero
- * Extension Headers: none
- o UDP header values:
 - * Checksum: the checksum MUST be calculated and the non-zero checksum included in the header
- o 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 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 category for two 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 methods for implementations.

[8.3.1. Reference Method](#)

The methodology for this metric is defined as Type-P-One-way-Delay-Poisson-Stream in [section 3.6 of \[RFC7679\]](#) and [section 4.6 of \[RFC7679\]](#) using the Type-P and Tmax defined under Fixed Parameters. 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 T_{max} . Also, when all packet delays are stored, the process which calculates the one-way delay value MUST enforce the T_{max} 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 [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](#)], 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 measurement protocol dictates the format of sequence numbers and time-stamps conveyed in the TWAMP-Test packet payload.

8.3.2. Packet Stream Generation

This section gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and 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 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 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 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 therefore a valid replacement for selecting a start time at random from a fixed interval.

These stream parameters will be specified as Run-time parameters.

8.3.3. Traffic Filtering (observation) Details

NA

8.3.4. Sampling Distribution

NA

8.3.5. Run-time Parameters and Data Format

Run-time 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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [Section 3 of \[RFC6991\]](#)). The UTC Time Zone is required by [Section 6.1 of \[RFC2330\]](#). When T0 is "all-zeros", a end time 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

Dst. This is the TWAMP Session-Sender.

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Dst waits for each packet from Src and sends a return packet to Src.

This 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

See subsection titles in Reference Definition for Latency Types.

8.4.2. Reference Definition

For all output types ---

T0 the start of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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>, one of the following sub-sections apply:

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 [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), $F(95\text{Percentile}) \geq 95\%$ 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.2.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.3.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [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, and 4.3.3 of [\[RFC6049\]](#). The formula is as follows:

$$\text{Max} = (\text{FiniteDelay}[j])$$

such that for some index, j , where $1 \leq j \leq N$
 $\text{FiniteDelay}[j] \geq \text{FiniteDelay}[n]$ 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

8.4.2.5. Std_Dev

The 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 [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, and 4.3.3 of [\[RFC6049\]](#). The formula is the classic calculation for standard deviation of a population.

Define Population Std_Dev_Delay as follows:
(where all packets n = 1 through N have a value for Delay[n],
and MeanDelay calculated as in 7.4.2.2), and SQRT[] is the
Square Root function:

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

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 resolution of
0.000000001 seconds (1.0 ns), and with lossless conversion to/
from
the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

8.4.3. Metric Units

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

- o 95Percentile
- o Mean
- o Min
- o Max
- o 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. In-situ
calibration 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
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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [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 additional indication that it is a calibration result. In any measurement, the measurement function SHOULD report its current estimate of 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 which is the result of system noise, and thus inaccurate.

[8.5.](#) Administrative items

[8.5.1.](#) Status

Current

[8.5.2.](#) Requester

This RFC number

[8.5.3.](#) Revision

1.0

[8.5.4.](#) Revision Date

YYYY-MM-DD

8.6. Comments and Remarks

None.

9. ICMP Round-trip Latency and Loss Registry Entries

This section specifies three initial registry entries for the ICMP Round-trip Latency, and another entry for ICMP Round-trip Loss Ratio.

IANA Note: Registry "Name" below specifies multiple registry entries, whose output format varies according to the <statistic> element of the name that specifies one form of statistical summary. There is an additional metric name for the Loss metric.

All column entries beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes two closely-related registry entries. As a result, IANA is also asked to assign corresponding URLs to each Named Metric.

9.1. Summary

This category includes multiple indexes to the registry entry: the element ID and metric name.

9.1.1. ID (Identifier)

IANA is asked to assign different numeric identifiers to each of the four Named Metrics.

9.1.2. Name

RTDelay_Active_IP-ICMP-SendOnRcv_RFCXXXXsec9_Seconds_<statistic>

where <statistic> is one of:

- o Mean
- o Min
- o Max

RTLoss_Active_IP-ICMP-SendOnRcv_RFCXXXXsec9_Percent_LossRatio

9.1.3. URIs

URL: <https://www.iana.org/> ... <name>

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), and 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:

- o Mean
- o Min
- o Max

RTLoss: This metric assesses the loss ratio of a stream of ICMP packets exchanged between two hosts (which are the two measurement points), and the Output is the Round-trip loss ratio for all successfully exchanged 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

Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip Delay Metric for IPPM", [RFC 2681](#), September 1999.

[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 [\[RFC2681\]](#) definition of "Round-trip-Delay between Src and Dst" 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 "Dst", and ultimately receive the corresponding return packet from "Dst" (when neither are 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 re-used in other IPPM literature to refer to different quantities, and cannot be used as a global variable name.

Morton, A., "Round-trip Packet Loss Metrics", [RFC 6673](#), August 2012.

[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 \[RFC2330\]](#):

- o IPv4 header values:
 - * DSCP: set to 0
 - * TTL: set to 255
 - * Protocol: Set to 01 (ICMP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 128 decimal (ICMP)
 - * Flow Label: set to zero
 - * Extension Headers: none
- o 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 Run-Time)

- o ICMP Payload

- * total of 32 bytes of random info, constant per test.

Other measurement parameters:

- o Tmax: a loss threshold waiting time

- * 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 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 methods for implementations.

9.3.1. Reference Method

The methodology for this metric is defined as Type-P-Round-trip-Delay-Poisson-Stream in [section 2.6 of RFC 2681 \[RFC2681\]](#) and [section 3.6 of RFC 2681 \[RFC2681\]](#) using the Type-P and Tmax defined under Fixed Parameters.

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 which 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 [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 expanded discussion of the instruction to "send a Type-P packet back to the Src as quickly as possible" in [Section 2.6 of RFC 2681 \[RFC2681\]](#). [Section 8 of \[RFC6673\]](#) presents additional requirements which MUST be included in the method of measurement for this metric.

9.3.2. Packet Stream Generation

This section gives the details of the packet traffic which is the basis for measurement. In IPPM metrics, this is called the Stream, and 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 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 Run-time 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 $RTD \geq incT$, 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

NA

9.3.4. Sampling Distribution

NA

9.3.5. Run-time Parameters and Data Format

Run-time 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 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 resolution of 0.0001 seconds (0.1 ms).

T0 a time, the start of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 Run-time parameters)

9.3.6. Roles

Src launches each packet and waits for return transmissions from Dst.

Dst waits for each packet from Src and sends a return packet to

Src.

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9.4. Output

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

9.4.1. Type

See subsection titles in Reference Definition for Latency Types.

LossRatio -- the count of lost packets to total packets sent is the basis for the loss ratio calculation as per [Section 6.1 of \[RFC6673\]](#).

9.4.2. Reference Definition

For all output types ---

T0 the start of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 Dst during the measurement interval.

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>, one of the following sub-sections apply:

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.2.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.3.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [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, and 4.3.3 of [\[RFC6049\]](#). The formula is as follows:

$$\text{Max} = (\text{FiniteDelay} [j])$$

such that for some index, j, where $1 \leq j \leq N$
 $\text{FiniteDelay}[j] \geq \text{FiniteDelay}[n]$ 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 resolution of 0.000000001

seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [[RFC5905](#)]

9.4.3. Metric Units

The <statistic> of Round-trip Delay is expressed in seconds, where <statistic> is one of:

- o Mean
- o Min
- o 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. In-situ calibration 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 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 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 which is the result of system noise, and thus inaccurate.

9.5. Administrative items

9.5.1. Status

Current

9.5.2. Requester

This RFC number

9.5.3. Revision

1.0

9.5.4. Revision Date

YYYY-MM-DD

9.6. Comments and Remarks

None

10. TCP Round-Trip Delay and Loss Registry Entries

This section specifies three initial registry entries for the Passive assessment of TCP Round-Trip Delay (RTD) and another entry for TCP Round-trip Loss Count.

IANA Note: Registry "Name" below specifies multiple registry entries, whose output format varies according to the <statistic> element of the name that specifies one form of statistical summary. There are two additional metric names for Singleton RT Delay and Packet Count metrics.

All column entries beside the ID, Name, Description, and Output Reference Method categories are the same, thus this section proposes four closely-related registry entries. As a result, IANA is also asked to assign corresponding URLs to each Named Metric.

10.1. Summary

This category includes multiple indexes to the registry entry: the element ID and metric name.

10.1.1. ID (Identifier)

IANA is asked to assign different numeric identifiers to each of the four Named Metrics.

10.1.2. Name

RTDelay_Passive_IP-TCP_RFCXXXXsec10_Seconds_<statistic>

where <statistic> is one of:

- o Mean
- o Min
- o Max

RTDelay_Passive_IP-TCP-HS_RFCXXXXsec10_Seconds_Singleton

Note that a mid-point observer only has the opportunity to compose a single RTDelay on the TCP Hand Shake.

RTLoss_Passive_IP-TCP_RFCXXXXsec10_Packet_Count

10.1.3. URIs

URL: <https://www.iana.org/> ... <name>

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 [[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:

- o Mean
- o Min
- o Max

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 Observation Point [[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 Definitions

Although there is no RFC that describes passive measurement of Round-Trip Delay, the parallel definition for Active measurement is:

Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip Delay Metric for IPPM", [RFC 2681](#), September 1999.

[RFC2681]

This metric definition uses 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 Observation Point [\[RFC7011\]](#) (OP) 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 OP to B (Reverse is B through OP to A).

Traffic filters reduce the packet stream 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} , \gg the Round-trip Delay in the Forward direction from OP to host B at time T' is $RTD_{fwd} \ll$ REQUIRES that 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 OP observed the Corresponding Packet at wire-time $T' + \text{RTD}_{\text{fwd}}$.

For a real number, RTD_{rev} , \gg the Round-trip Delay in the Reverse direction from OP to host A at time T' is $RTD_{rev} \ll$ REQUIRES that 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 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 $T' + RTD_{rev}$ above) is:

$$RTDelay = RTD_{fwd} + RTD_{rev}$$

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

When the Qualified and Corresponding Packets are a TCP-SYN and a TCP-

SYN-ACK, then $RTD_{fwd} == RTD_{HS_{fwd}}$.

When the Qualified and Corresponding Packets are a TCP-SYN-ACK and a TCP-ACK, then $RTD_{rev} == RTD_{HS_{rev}}$.

The REQUIRED Composition Function for a singleton of Round-trip Delay

for the connection Hand Shake:

$$RTDelay_{HS} = RTD_{HS_{fwd}} + RTD_{HS_{rev}}$$

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:

- o 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.
- o Duplicate segments: [Section 2 of \[RFC5560\]](#) defines identical packets and is suitable for evaluation of TCP packets to detect duplication. Observation of duplicate segments *without a

corresponding gap* indicates loss on the path following the OP

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(because they overlap part of the delivered sequence numbers already observed at OP).

Each observation of an out-of-order or duplicate infers a singleton of loss, but composition of Round-trip Loss Counts will be conducted over a measurement interval which 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 a the two single-direction counts of inferred loss is:

$$RTL_{Loss} = RTL_{fwd} + RTL_{rev}$$

10.2.2. Fixed Parameters

Traffic Filters:

- o IPv4 header values:
 - * DSCP: set to 0
 - * Protocol: Set to 06 (TCP)
- o IPv6 header values:
 - * DSCP: set to 0
 - * Hop Count: set to 255
 - * Next Header: set to 6 (TCP)
 - * Flow Label: set to zero
 - * Extension Headers: none
- o TCP header values:
 - * Flags: ACK, SYN, FIN, set as required
 - * Timestamp Option (TSopt): Set
 - + [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 unambiguous methods for implementations.

10.3.1. Reference Methods

The foundation methodology for this metric is defined in [Section 4 of \[RFC7323\]](#) using the Timestamp Option with modifications that allow application at a mid-path Observation Point (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 sanity check on other Composed values of RTDelay.

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

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 their 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 Timestamp echo (TSecr) 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

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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 which 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 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 Re-ordered from OOO due to loss, because sequence number gap is filled during the same RTDelay window. Segments detected as re-ordered according to [RFC4737] MUST reduce the Loss Count inferred from Out-of-order segments.

Spurious (unneeded) retransmissions (observed as duplicates) can also be reduced 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, described in section 3 of [Trammell-14].

10.3.2. Packet Stream Generation

NA

10.3.3. Traffic Filtering (observation) Details

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

10.3.4. Sampling Distribution

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

10.3.5. Run-time Parameters and Data Format

Run-time 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 (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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 Td is to be interpreted as the Duration of the measurement interval. The start time is controlled through other means.

Td Optionally, the end of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 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, and synonymous with an IP address.

host B replies with the SYN-ACK packet to open the connection, and synonymous with an IP address.

10.4. Output

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

10.4.1. Type

See subsection titles in Reference Definition for RTDelay Types.

For RTLoss -- the count of lost packets.

10.4.2. Reference Definition

For all output types ---

T0 the start of a measurement interval, (format "date-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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-and-time" as specified in [Section 5.6 of \[RFC3339\]](#), see also [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 B effectively ends the interval.

... ..

For RTDelay_HS -- the Round trip delay of the Handshake.

For RTLoss -- the count of lost packets.

For each <statistic>, one of the following sub-sections apply:

10.4.2.1. 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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.2.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [Section 5 of \[RFC6703\]](#) for background on this analysis choice.

See [section 4.3.2 of \[RFC6049\]](#) for details on calculating this statistic, and 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 resolution of 0.000000001 seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [\[RFC5905\]](#)

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 [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, and 4.3.3 of [\[RFC6049\]](#). The formula is as follows:

$$\text{Max} = (\text{FiniteDelay} [j])$$

such that for some index, j, where $1 \leq j \leq N$
 $\text{FiniteDelay}[j] \geq \text{FiniteDelay}[n]$ 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 resolution of 0.000000001

seconds (1.0 ns), and with lossless conversion to/from the 64-bit NTP timestamp as per [section 6](#) of RFC [[RFC5905](#)]

10.4.3. Metric Units

The <statistic> of Round-trip Delay is expressed in seconds, where <statistic> is one of:

- o Mean
- o Min
- o Max

The Round-trip Delay of the Hand Shake 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 B, where the active measurement represents the ground-truth.

10.5. Administrative items

10.5.1. Status

Current

10.5.2. Requester

This RFC number

10.5.3. Revision

1.0

10.5.4. Revision Date

YYYY-MM-DD

10.6. Comments and Remarks

None.

11. Security Considerations

These registry entries represent no known implications for Internet Security. Each IETF Metric definition referenced above contains a Security Considerations section. Further, the LMAP Framework [[RFC7594](#)] provides both security and privacy considerations for measurements.

There are potential privacy considerations for observed traffic, particularly for passive metrics 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 is requested to populate The Performance Metrics Registry defined in [[I-D.ietf-ippm-metric-registry](#)] with the values defined in sections [4](#) through [10](#).

See the IANA Considerations section of [[I-D.ietf-ippm-metric-registry](#)] for additional requests and considerations.

13. Acknowledgements

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14. References

14.1. Normative References

- [I-D.ietf-ippm-metric-registry]
Bagnulo, M., Claise, B., Eardley, P., and A. Morton,
"Registry for Performance Metrics", Internet Draft (work
in progress) [draft-ietf-ippm-metric-registry](#), 2019.
- [RFC1035] Mockapetris, P., "Domain names - implementation and
specification", STD 13, [RFC 1035](#), DOI 10.17487/RFC1035,
November 1987, <<https://www.rfc-editor.org/info/rfc1035>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
Requirement Levels", [BCP 14](#), [RFC 2119](#),
DOI 10.17487/RFC2119, March 1997,
<<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC2330] Paxson, V., Almes, G., Mahdavi, J., and M. Mathis,
"Framework for IP Performance Metrics", [RFC 2330](#),
DOI 10.17487/RFC2330, May 1998,
<<https://www.rfc-editor.org/info/rfc2330>>.
- [RFC2681] Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip
Delay Metric for IPPM", [RFC 2681](#), DOI 10.17487/RFC2681,
September 1999, <[https://www.rfc-editor.org/info/
rfc2681](https://www.rfc-editor.org/info/rfc2681)>.
- [RFC3339] Klyne, G. and C. Newman, "Date and Time on the Internet:
Timestamps", [RFC 3339](#), DOI 10.17487/RFC3339, July 2002,
<<https://www.rfc-editor.org/info/rfc3339>>.
- [RFC3393] Demichelis, C. and P. Chimento, "IP Packet Delay
Variation
Metric for IP Performance Metrics (IPPM)", [RFC 3393](#),
DOI 10.17487/RFC3393, November 2002,
<<https://www.rfc-editor.org/info/rfc3393>>.
- [RFC3432] Raisanen, V., Grotefeld, G., and A. Morton, "Network
performance measurement with periodic streams", [RFC 3432](#),
DOI 10.17487/RFC3432, November 2002,
<<https://www.rfc-editor.org/info/rfc3432>>.
- [RFC4737] Morton, A., Ciavattone, L., Ramachandran, G., Shalunov,
S., and J. Perser, "Packet Reordering Metrics", [RFC 4737](#),
DOI 10.17487/RFC4737, November 2006,
<<https://www.rfc-editor.org/info/rfc4737>>.
- [RFC5357] Hedayat, K., Krzanowski, R., Morton, A., Yum, K., and J.
Babiarz, "A Two-Way Active Measurement Protocol (TWAMP)",
[RFC 5357](#), DOI 10.17487/RFC5357, October 2008,
<<https://www.rfc-editor.org/info/rfc5357>>.

- [RFC5560] Uijterwaal, H., "A One-Way Packet Duplication Metric", [RFC 5560](#), DOI 10.17487/RFC5560, May 2009, <<https://www.rfc-editor.org/info/rfc5560>>.
- [RFC5905] 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>>.
- [RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", [RFC 6020](#), DOI 10.17487/RFC6020, October 2010, <<https://www.rfc-editor.org/info/rfc6020>>.
- [RFC6049] Morton, A. and E. Stephan, "Spatial Composition of Metrics", [RFC 6049](#), DOI 10.17487/RFC6049, January 2011, <<https://www.rfc-editor.org/info/rfc6049>>.
- [RFC6673] Morton, A., "Round-Trip Packet Loss Metrics", [RFC 6673](#), DOI 10.17487/RFC6673, August 2012, <<https://www.rfc-editor.org/info/rfc6673>>.
- [RFC6991] Schoenwaelder, J., Ed., "Common YANG Data Types", [RFC 6991](#), DOI 10.17487/RFC6991, July 2013, <<https://www.rfc-editor.org/info/rfc6991>>.
- [RFC7011] Claise, B., Ed., Trammell, B., Ed., and P. Aitken, "Specification of the IP Flow Information Export (IPFIX) Protocol for the Exchange of Flow Information", STD 77, [RFC 7011](#), DOI 10.17487/RFC7011, September 2013, <<https://www.rfc-editor.org/info/rfc7011>>.
- [RFC7323] Borman, D., Braden, B., Jacobson, V., and R. Scheffenegger, Ed., "TCP Extensions for High Performance", [RFC 7323](#), DOI 10.17487/RFC7323, September 2014, <<https://www.rfc-editor.org/info/rfc7323>>.
- [RFC7679] Almes, G., Kalidindi, S., Zekauskas, M., and A. Morton, Ed., "A One-Way Delay Metric for IP Performance Metrics (IPPM)", STD 81, [RFC 7679](#), DOI 10.17487/RFC7679, January 2016, <<https://www.rfc-editor.org/info/rfc7679>>.
- [RFC7680] 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>>.

- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in [RFC 2119](#) Key Words", [BCP 14](#), [RFC 8174](#), DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [Strowes] Strowes, S., "Passively Measuring TCP Round Trip Times, Communications of the ACM, Vol. 56 No. 10, Pages 57-64", September 2013.
- [Trammell-14]
Trammell, B., "Inline Data Integrity Signals for Passive Measurement, In: Dainotti A., Mahanti A., Uhlig S. (eds) Traffic Monitoring and Analysis. TMA 2014. Lecture Notes in Computer Science, vol 8406. Springer, Berlin, Heidelberg https://link.springer.com/chapter/10.1007/978-3-642-54999-1_2", March 2014.

14.2. Informative References

- [RFC1242] Bradner, S., "Benchmarking Terminology for Network Interconnection Devices", [RFC 1242](#), DOI 10.17487/RFC1242, July 1991, <<https://www.rfc-editor.org/info/rfc1242>>.
- [RFC5481] 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>>.
- [RFC6390] Clark, A. and B. Claise, "Guidelines for Considering New Performance Metric Development", [BCP 170](#), [RFC 6390](#), DOI 10.17487/RFC6390, October 2011, <<https://www.rfc-editor.org/info/rfc6390>>.
- [RFC6703] Morton, A., Ramachandran, G., and G. Maguluri, "Reporting IP Network Performance Metrics: Different Points of View", [RFC 6703](#), DOI 10.17487/RFC6703, August 2012, <<https://www.rfc-editor.org/info/rfc6703>>.
- [RFC7594] Eardley, P., Morton, A., Bagnulo, M., Burbridge, T., Aitken, P., and A. Akhter, "A Framework for Large-Scale Measurement of Broadband Performance (LMAP)", [RFC 7594](#), DOI 10.17487/RFC7594, September 2015, <<https://www.rfc-editor.org/info/rfc7594>>.

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