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Spatial Composition of Metrics
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Abstract

This memo utilizes IP Performance Metrics that are applicable to both complete paths and sub-paths, and defines relationships to compose a complete path metric from the sub-path metrics with some accuracy w.r.t. the actual metrics. This is called Spatial Composition in RFC 2330. The memo refers to the Framework for Metric Composition, and provides background and motivation for combining metrics to derive others. The descriptions of several composed metrics and statistics follow.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 (Bradner, S., “Key words for use in RFCs to Indicate Requirement Levels,” March 1997.) [RFC2119].

In this memo, the characters "<=" should be read as "less than or equal to" and ">=" as "greater than or equal to".

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1. Introduction

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The IP Performance Metrics (IPPM) framework [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics," May 1998.) describes two forms of metric composition, spatial and temporal. The composition framework [RFC5835] (Morton, A. and S. Van den Berghe, "Framework for Metric Composition," April 2010.) expands and further qualifies these original forms into three categories. This memo describes Spatial Composition, one of the categories of metrics under the umbrella of the composition framework. Spatial composition encompasses the definition of performance metrics that are applicable to a complete path, based on metrics collected on various sub-paths.
The main purpose of this memo is to define the deterministic functions that yield the complete path metrics using metrics of the sub-paths. The effectiveness of such metrics is dependent on their usefulness in analysis and applicability with practical measurement methods.
The relationships may involve conjecture, and [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics," May 1998.) lists four points that the metric definitions should include:

- the specific conjecture applied to the metric and assumptions of the statistical model of the process being measured (if any, see [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics," May 1998.) section 12),

- a justification of the practical utility of the composition in terms of making accurate measurements of the metric on the path,

- a justification of the usefulness of the composition in terms of making analysis of the path using A-frame concepts more effective, and *an analysis of how the conjecture could be incorrect.

Also, [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, “Framework for IP Performance Metrics,” May 1998.) gives an example using the conjecture that the delay of a path is very nearly the sum of the delays of the exchanges and clouds of the corresponding path digest. This example is particularly relevant to those who wish to assess the performance of an Inter-domain path without direct measurement, and the performance estimate of the complete path is related to the measured results for various sub-paths instead. Approximate functions between the sub-path and complete path metrics are useful, with knowledge of the circumstances where the relationships are/are not applicable. For example, we would not expect that delay singletons from each sub-path would sum to produce an accurate estimate of a delay singleton for the complete path (unless all the delays were essentially constant - very unlikely). However, other delay statistics (based on a reasonable sample size) may have a sufficiently large set of circumstances where they are applicable.

1.1. Motivation

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One-way metrics defined in other RFCs (such as [RFC2679] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Delay Metric for IPPM,” September 1999.) and [RFC2680] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Packet Loss Metric for IPPM,” September 1999.)) all assume that the measurement can be practically carried out between the source and the destination of interest. Sometimes there are reasons that the measurement cannot be executed from the source to the destination. For instance, the measurement path may cross several independent domains that have conflicting policies, measurement tools and methods, and measurement time assignment. The solution then may be the composition of several sub-path measurements. This means each domain performs the One-way measurement on a sub path between two nodes that are involved in the complete path following its own policy, using its own measurement tools and methods, and using its own measurement timing. Under the appropriate conditions, one can combine the sub-path One-way metric results to estimate the complete path One-way measurement metric with some degree of accuracy.

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2. Scope and Application

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2.1. Scope of work

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For the primary IPPM metrics of Loss [RFC2680] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Packet Loss Metric for IPPM,” September 1999.), Delay [RFC2679] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Delay Metric for IPPM,” September 1999.), and Delay Variation [RFC3393] (Demichelis, C. and P. Chimento, “IP Packet Delay Variation Metric for IP Performance Metrics (IPPM),” November 2002.), this memo gives a set of metrics that can be composed from the same or similar sub-path metrics. This means that the composition function may utilize:

- the same metric for each sub-path;
- multiple metrics for each sub-path (possibly one that is the same as the complete path metric);
- a single sub-path metric that is different from the complete path metric;
- different measurement techniques like active [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, “Framework for IP Performance Metrics,” May 1998.), [RFC3432] (Raisanen, V., Grotefeld, G., and A. Morton, “Network performance measurement with periodic streams,” November 2002.) and passive [RFC5474] (Duffield, N., Chiou, D., Claise, B., Greenberg, A., Grossglauser, M., and J. Rexford, “A Framework for Packet Selection and Reporting,” March 2009.).

We note a possibility: Using a complete path metric and all but one sub-path metric to infer the performance of the missing sub-path, especially when the "last" sub-path metric is missing. However, such de-composition calculations, and the corresponding set of issues they raise, are beyond the scope of this memo.

2.2. Application

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The composition framework [RFC5835] (Morton, A. and S. Van den Berghe, “Framework for Metric Composition,” April 2010.) requires the specification of the applicable circumstances for each metric. In particular, each section addresses whether the metric:
Requires the same test packets to traverse all sub-paths, or may use similar packets sent and collected separately in each sub-path.
Requires homogeneity of measurement methodologies, or can allow a degree of flexibility (e.g., active or passive methods produce the

"same" metric). Also, the applicable sending streams will be specified, such as Poisson, Periodic, or both.
Needs information or access that will only be available within an operator's domain, or is applicable to Inter-domain composition.
Requires synchronized measurement start and stop times in all sub-paths, or largely overlapping, or no timing requirements.
Requires assumption of sub-path independence w.r.t. the metric being defined/composed, or other assumptions.
Has known sources of inaccuracy/error, and identifies the sources.

2.3. Incomplete Information

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In practice, when measurements cannot be initiated on a sub-path (and perhaps the measurement system gives up during the test interval), then there will not be a value for the sub-path reported, and the entire test result SHOULD be recorded as "undefined". This case should be distinguished from the case where the measurement system continued to send packets throughout the test interval, but all were declared lost.
When a composed metric requires measurements from sub paths A, B, and C, and one or more of the sub-path results are undefined, then the composed metric SHOULD also be recorded as undefined.

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3. Common Specifications for Composed Metrics

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To reduce the redundant information presented in the detailed metrics sections that follow, this section presents the specifications that are common to two or more metrics. The section is organized using the same subsections as the individual metrics, to simplify comparisons.
Also, the following index variables represent the following:

- m = index for packets sent
- n = index for packets received
- s = index for involved sub-paths

3.1. Name: Type-P

TOC

All metrics use the Type-P convention as described in [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, “Framework for IP

Performance Metrics," May 1998.). The rest of the name is unique to each metric.

3.1.1. Metric Parameters

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*Src, the IP address of a host

*Dst, the IP address of a host

*T, a time (start of test interval)

*Tf, a time (end of test interval)

*lambda, a rate in reciprocal seconds (for Poisson Streams)

*incT, the nominal duration of inter-packet interval, first bit to first bit (for Periodic Streams)

*T0, a time that MUST be selected at random from the interval [T, T+dT] to start generating packets and taking measurements (for Periodic Streams)

*TstampSrc, the wire time of the packet as measured at MP(Src)

*TstampDst, the wire time of the packet as measured at MP(Dst), assigned to packets that arrive within a "reasonable" time.

*Tmax, a maximum waiting time for packets at the destination, set sufficiently long to disambiguate packets with long delays from packets that are discarded (lost), thus the distribution of delay is not truncated.

*M, the total number of packets sent between T0 and Tf

*N, the total number of packets received at Dst (sent between T0 and Tf)

*S, the number of sub-paths involved in the complete Src-Dst path

*Type-P, as defined in [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics," May 1998.), which includes any field that may affect a packet's treatment as it traverses the network

In metric names, the term <Sample> is intended to be replaced by the name of the method used to define a sample of values of parameter TstampSrc. This can be done in several ways, including:

1. Poisson: a pseudo-random Poisson process of rate lambda, whose values fall between T and Tf. The time interval between successive values of TstampSrc will then average 1/lambda, as per [RFC2330] (Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics," May 1998.).

2. Periodic: a periodic stream process with pseudo-random start time T0 between T and dT, and nominal inter-packet interval incT, as per [RFC3432] (Raisanen, V., Grotefeld, G., and A. Morton, "Network performance measurement with periodic streams," November 2002.).

3.1.2. Definition and Metric Units

TOC

This section is unique for every metric.

3.1.3. Discussion and other details

TOC

This section is unique for every metric.

3.1.4. Statistic:

TOC

This section is unique for every metric.

3.1.5. Composition Function

TOC

This section is unique for every metric.

TOC

3.1.6. Statement of Conjecture and Assumptions

This section is unique for each metric. The term "ground truth" frequently used in these sections and it is defined in section 4.7 of [RFC5835] (Morton, A. and S. Van den Berghe, “Framework for Metric Composition,” April 2010.).

3.1.7. Justification of the Composition Function

TOC

It is sometimes impractical to conduct active measurements between every Src-Dst pair. Since the full mesh of N measurement points grows as N x N, the scope of measurement may be limited by testing resources. There may be varying limitations on active testing in different parts of the network. For example, it may not be possible to collect the desired sample size in each test interval when access link speed is limited, because of the potential for measurement traffic to degrade the user traffic performance. The conditions on a low-speed access link may be understood well-enough to permit use of a small sample size/ rate, while a larger sample size/rate may be used on other sub-paths. Also, since measurement operations have a real monetary cost, there is value in re-using measurements where they are applicable, rather than launching new measurements for every possible source-destination pair.

3.1.8. Sources of Deviation from the Ground Truth

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3.1.8.1. Sub-path List Differs from Complete Path

TOC

The measurement packets, each having source and destination addresses intended for collection at edges of the sub-path, may take a different specific path through the network equipment and links when compared to packets with the source and destination addresses of the complete path. Examples sources of parallel paths include Equal Cost Multi-Path and parallel (or bundled) links. Therefore, the performance estimated from the composition of sub-path measurements may differ from the performance experienced by packets on the complete path. Multiple measurements employing sufficient sub-path address pairs might produce bounds on the extent of this error.
We also note the possibility of re-routing during a measurement interval, as it may affect the correspondence between packets

traversing the complete path and the sub-paths that were "involved" prior to the re-route.

3.1.8.2. Sub-path Contains Extra Network Elements

TOC

Related to the case of an alternate path described above is the case where elements in the measured path are unique to measurement system connectivity. For example, a measurement system may use a dedicated link to a LAN switch, and packets on the complete path do not traverse that link. The performance of such a dedicated link would be measured continuously, and its contribution to the sub-path metrics SHOULD be minimized as a source of error.

3.1.8.3. Sub-paths Have Incomplete Coverage

TOC

Measurements of sub-path performance may not cover all the network elements on the complete path. For example, the network exchange points might be excluded unless a cooperative measurement is conducted. In this example, test packets on the previous sub-path are received just before the exchange point and test packets on the next sub-path are injected just after the same exchange point. Clearly, the set of sub-path measurements SHOULD cover all critical network elements in the complete path.

3.1.8.4. Absence of route

TOC

At a specific point in time, no viable route exists between the complete path source and destination. The routes selected for one or more sub-paths therefore differs from the complete path. Consequently, spatial composition may produce finite estimation of a ground truth metric (see section 4.7 of [RFC5835] (Morton, A. and S. Van den Berghe, “Framework for Metric Composition,” April 2010.)) between a source and a destination, even when the route between them is undefined.

3.1.9. Specific cases where the conjecture might fail

TOC

This section is unique for most metrics (see the metric-specific sections).

For delay-related metrics, One-way delay always depends on packet size and link capacity, since it is measured in [RFC2679] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Delay Metric for IPPM,” September 1999.) from first bit to last bit. If the size of an IP packet changes on route (due to encapsulation), this can influence delay performance. However, the main error source may be the additional processing associated with encapsulation and encryption/decryption if not experienced or accounted for in sub-path measurements.
Fragmentation is a major issue for composition accuracy, since all metrics require all fragments to arrive before proceeding, and fragmented complete path performance is likely to be different from performance with non-fragmented packets and composed metrics based on non-fragmented sub-path measurements.
Highly manipulated routing can cause measurement error if not expected and compensated. For example, policy-based MPLS routing could modify the class of service for the sub-paths and complete path.

3.1.10. Application of Measurement Methodology

TOC

The methodology:
SHOULD use similar packets sent and collected separately in each sub-path, where "similar" in this case means that the Type-P contains as many equal attributes as possible, while recognizing that there will be differences. Note that Type-P includes stream characteristics (e.g., Poisson, Periodic).
Allows a degree of flexibility regarding test stream generation (e.g., active or passive methods can produce an equivalent result, but the lack of control over the source, timing and correlation of passive measurements is much more challenging).
Poisson and/or Periodic streams are RECOMMENDED.
Applies to both Inter-domain and Intra-domain composition.
SHOULD have synchronized measurement time intervals in all sub-paths, but largely overlapping intervals MAY suffice.
Assumption of sub-path independence w.r.t. the metric being defined/ composed is REQUIRED.

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4. One-way Delay Composed Metrics and Statistics

TOC

TOC

4.1. Name: Type-P-Finite-One-way-Delay-<Sample>-Stream

This metric is a necessary element of Delay Composition metrics, and its definition does not formally exist elsewhere in IPPM literature.

4.1.1. Metric Parameters

TOC

See the common parameters section above.

4.1.2. Definition and Metric Units

TOC

Using the parameters above, we obtain the value of Type-P-One-way-Delay singleton as per [RFC2679] (Almes, G., Kalidindi, S., and M. Zekauskas, "A One-way Delay Metric for IPPM," September 1999.).
For each packet [i] that has a finite One-way Delay (in other words, excluding packets which have undefined one-way delay):
Type-P-Finite-One-way-Delay-<Sample>-Stream[i] =
FiniteDelay[i] = TstampDst - TstampSrc
The units of measure for this metric are time in seconds, expressed in sufficiently low resolution to convey meaningful quantitative information. For example, resolution of microseconds is usually sufficient.

4.1.3. Discussion and other details

TOC

The "Type-P-Finite-One-way-Delay" metric permits calculation of the sample mean statistic. This resolves the problem of including lost packets in the sample (whose delay is undefined), and the issue with the informal assignment of infinite delay to lost packets (practical systems can only assign some very large value).
The Finite-One-way-Delay approach handles the problem of lost packets by reducing the event space. We consider conditional statistics, and estimate the mean one-way delay conditioned on the event that all packets in the sample arrive at the destination (within the specified waiting time, Tmax). This offers a way to make some valid statements about one-way delay, and at the same time avoiding events with undefined outcomes. This approach is derived from the treatment of lost packets in [RFC3393] (Demichelis, C. and P. Chimento, "IP Packet Delay Variation Metric for IP Performance Metrics (IPPM)," November 2002.), and is similar to [Y.1540] (ITU-T Recommendation Y.1540, "Internet

protocol data communication service - IP packet transfer and availability performance parameters," November 2007.) .

4.1.4. Statistic:

TOC

All statistics defined in [RFC2679] (Almes, G., Kalidindi, S., and M. Zekauskas, "A One-way Delay Metric for IPPM," September 1999.) are applicable to the finite one-way delay,and additional metrics are possible, such as the mean (see below).

4.2. Name: Type-P-Finite-Composite-One-way-Delay-Mean

TOC

This section describes a statistic based on the Type-P-Finite-One-way-Delay-<Sample>-Stream metric.

4.2.1. Metric Parameters

TOC

See the common parameters section above.

4.2.2. Definition and Metric Units of the Mean Statistic

TOC

We define
Type-P-Finite-One-way-Delay-Mean =

```
                              N
                             ---
                        1    \
           = MeanDelay = - *  >   (FiniteDelay [n])
                        N    /
                             ---
                            n = 1
```

where all packets n= 1 through N have finite singleton delays.
The units of measure for this metric are time in seconds, expressed in sufficiently fine resolution to convey meaningful quantitative information. For example, resolution of microseconds is usually sufficient.

4.2.3. Discussion and other details

TOC

The Type-P-Finite-One-way-Delay-Mean metric requires the conditional delay distribution described in section 5.1.

4.2.4. Statistic:

TOC

This metric, a mean, does not require additional statistics.

4.2.5. Composition Function: Sum of Means

TOC

The Type-P-Finite-Composite-One-way-Delay-Mean, or CompMeanDelay, for the complete Source to Destination path can be calculated from sum of the Mean Delays of all its S constituent sub-paths.
Then the
Type-P-Finite-Composite-One-way-Delay-Mean =

```
                   S
                  ---
                  \
 = CompMeanDelay =  >   (MeanDelay [s])
                  /
                  ---
                 s = 1
```

where sub-paths s = 1 to S are involved in the complete path.

4.2.6. Statement of Conjecture and Assumptions

TOC

The mean of a sufficiently large stream of packets measured on each sub-path during the interval [T, Tf] will be representative of the ground truth mean of the delay distribution (and the distributions themselves are sufficiently independent), such that the means may be added to produce an estimate of the complete path mean delay.
It is assumed that the one-way delay distributions of the sub-paths and the complete path are continuous. The mean of multi-modal distributions have the unfortunate property that such a value may never occur.

TOC

4.2.7. Justification of the Composition Function

See the common section.

4.2.8. Sources of Deviation from the Ground Truth

TOC

See the common section.

4.2.9. Specific cases where the conjecture might fail

TOC

If any of the sub-path distributions are multi-modal, then the measured means may not be stable, and in this case the mean will not be a particularly useful statistic when describing the delay distribution of the complete path.
The mean may not be a sufficiently robust statistic to produce a reliable estimate, or to be useful even if it can be measured.
If a link contributing non-negligible delay is erroneously included or excluded, the composition will be in error.

4.2.10. Application of Measurement Methodology

TOC

The requirements of the common section apply here as well.

4.3. Name: Type-P-Finite-Composite-One-way-Delay-Minimum

TOC

This section describes is a statistic based on the Type-P-Finite-One-way-Delay-<Sample>-Stream metric, and the composed metric based on that statistic.

4.3.1. Metric Parameters

TOC

See the common parameters section above.

TOC

4.3.2. Definition and Metric Units of the Minimum Statistic

We define
Type-P-Finite-One-way-Delay-Minimum =

```
              = MinDelay = (FiniteDelay [j])

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

where all packets n = 1 through N have finite singleton delays.
The units of measure for this metric are time in seconds, expressed in sufficiently fine resolution to convey meaningful quantitative information. For example, resolution of microseconds is usually sufficient.

4.3.3. Discussion and other details

TOC

The Type-P-Finite-One-way-Delay-Minimum metric requires the conditional delay distribution described in section 5.1.3.

4.3.4. Statistic:

TOC

This metric, a minimum, does not require additional statistics.

4.3.5. Composition Function: Sum of Minima

TOC

The Type-P-Finite-Composite-One-way-Delay-Minimum, or CompMinDelay, for the complete Source to Destination path can be calculated from sum of the Minimum Delays of all its S constituent sub-paths.
Then the
Type-P-Finite-Composite-One-way-Delay-Minimum =

```
                                    S
                                   ---
                                   \
                  = CompMinDelay =   >  (MinDelay [s])
                                   /
                                   ---
                                  s = 1
```

4.3.6. Statement of Conjecture and Assumptions

TOC

The minimum of a sufficiently large stream of packets measured on each sub-path during the interval [T, Tf] will be representative of the ground truth minimum of the delay distribution (and the distributions themselves are sufficiently independent), such that the minima may be added to produce an estimate of the complete path minimum delay.
It is assumed that the one-way delay distributions of the sub-paths and the complete path are continuous.

4.3.7. Justification of the Composition Function

TOC

See the common section.

4.3.8. Sources of Deviation from the Ground Truth

TOC

See the common section.

4.3.9. Specific cases where the conjecture might fail

TOC

If the routing on any of the sub-paths is not stable, then the measured minimum may not be stable. In this case the composite minimum would tend to produce an estimate for the complete path that may be too low for the current path.

4.3.10. Application of Measurement Methodology

TOC

The requirements of the common section apply here as well.

5. Loss Metrics and Statistics

TOC

5.1. Type-P-Composite-One-way-Packet-Loss-Empirical-Probability

TOC

5.1.1. Metric Parameters:

TOC

Same as section 4.1.1.

5.1.2. Definition and Metric Units

TOC

Using the parameters above, we obtain the value of Type-P-One-way-Packet-Loss singleton and stream as per [RFC2680] (Almes, G., Kalidindi, S., and M. Zekauskas, “A One-way Packet Loss Metric for IPPM,” September 1999.).
We obtain a sequence of pairs with elements as follows:

*TstampSrc, as above

*L, either zero or one, where L=1 indicates loss and L=0 indicates arrival at the destination within TstampSrc + Tmax.

5.1.3. Discussion and other details

TOC

None.

5.1.4. Statistic: Type-P-One-way-Packet-Loss-Empirical-Probability

TOC

Given the stream parameter M, the number of packets sent, we can define the Empirical Probability of Loss Statistic (Ep), consistent with Average Loss in [RFC2680], as follows:
Type-P-One-way-Packet-Loss-Empirical-Probability =

```
                   M
                  ---
             1    \
     = Ep =  - *   >  (L[m])
             M    /
                  ---
                 m = 1
```

where all packets m = 1 through M have a value for L.

5.1.5. Composition Function: Composition of Empirical Probabilities

TOC

The Type-P-One-way-Composite-Packet-Loss-Empirical-Probability, or CompEp for the complete Source to Destination path can be calculated by combining Ep of all its constituent sub-paths (Ep1, Ep2, Ep3, ... Epn) as
Type-P-Composite-One-way-Packet-Loss-Empirical-Probability =

```
     = CompEp = 1 - {(1 - Ep1) x (1 - Ep2) x (1 - Ep3) x ... x (1 - EpS)}
```

If any Eps is undefined in a particular measurement interval, possibly because a measurement system failed to report a value, then any CompEp that uses sub-path s for that measurement interval is undefined.

5.1.6. Statement of Conjecture and Assumptions

TOC

The empirical probability of loss calculated on a sufficiently large stream of packets measured on each sub-path during the interval [T, Tf] will be representative of the ground truth empirical loss probability (and the probabilities themselves are sufficiently independent), such that the sub-path probabilities may be combined to produce an estimate of the complete path empirical loss probability.

5.1.7. Justification of the Composition Function

TOC

See the common section.

TOC

5.1.8. Sources of Deviation from the Ground Truth

See the common section.

5.1.9. Specific cases where the conjecture might fail

TOC

A concern for loss measurements combined in this way is that root causes may be correlated to some degree.
For example, if the links of different networks follow the same physical route, then a single catastrophic event like a fire in a tunnel could cause an outage or congestion on remaining paths in multiple networks. Here it is important to ensure that measurements before the event and after the event are not combined to estimate the composite performance.
Or, when traffic volumes rise due to the rapid spread of an email-borne worm, loss due to queue overflow in one network may help another network to carry its traffic without loss.

5.1.10. Application of Measurement Methodology

TOC

See the common section.

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6. Delay Variation Metrics and Statistics

TOC

6.1. Name: Type-P-One-way-pdv-refmin-<Sample>-Stream

TOC

This packet delay variation (PDV) metric is a necessary element of Composed Delay Variation metrics, and its definition does not formally exist elsewhere in IPPM literature (with the exception of [RFC5481] (Morton, A. and B. Claise, “Packet Delay Variation Applicability Statement,” March 2009.) .

TOC

6.1.1. Metric Parameters:

In addition to the parameters of section 4.1.1:

- *TstampSrc[i], the wire time of packet[i] as measured at MP(Src) (measurement point at the source)

- *TstampDst[i], the wire time of packet[i] as measured at MP(Dst), assigned to packets that arrive within a "reasonable" time.

- *B, a packet length in bits

- *F, a selection function unambiguously defining the packets from the stream that are selected for the packet-pair computation of this metric. F(current packet), the first packet of the pair, MUST have a valid Type-P-Finite-One-way-Delay less than Tmax (in other words, excluding packets which have undefined one-way delay) and MUST have been transmitted during the interval T, Tf. The second packet in the pair, F(min_delay packet) MUST be the packet with the minimum valid value of Type-P-Finite-One-way-Delay for the stream, in addition to the criteria for F(current packet). If multiple packets have equal minimum Type-P-Finite-One-way-Delay values, then the value for the earliest arriving packet SHOULD be used.

- *MinDelay, the Type-P-Finite-One-way-Delay value for F(min_delay packet) given above.

- *N, the number of packets received at the Destination meeting the F(current packet) criteria.

6.1.2. Definition and Metric Units

TOC

Using the definition above in section 5.1.2, we obtain the value of Type-P-Finite-One-way-Delay-<Sample>-Stream[n], the singleton for each packet[i] in the stream (a.k.a. FiniteDelay[i]).
For each packet[n] that meets the F(first packet) criteria given above:
Type-P-One-way-pdv-refmin-<Sample>-Stream[n] =
PDV[n] = FiniteDelay[n] – MinDelay
where PDV[i] is in units of time in seconds, expressed in sufficiently fine resolution to convey meaningful quantitative information. For example, resolution of microseconds is usually sufficient.

TOC

6.1.3. Discussion and other details

This metric produces a sample of delay variation normalized to the minimum delay of the sample. The resulting delay variation distribution is independent of the sending sequence (although specific FiniteDelay values within the distribution may be correlated, depending on various stream parameters such as packet spacing). This metric is equivalent to the IP Packet Delay Variation parameter defined in [Y.1540] (ITU-T Recommendation Y.1540, "Internet protocol data communication service - IP packet transfer and availability performance parameters," November 2007.).

6.1.4. Statistics: Mean, Variance, Skewness, Quantile

TOC

We define the mean PDV as follows (where all packets n = 1 through N have a value for PDV[n]):
Type-P-One-way-pdv-refmin-Mean = MeanPDV =

```
                N
               ---
          1    \
          - *   >   (PDV[n])
          N    /
               ---
             n = 1
```

We define the variance of PDV as follows:
Type-P-One-way-pdv-refmin-Variance = VarPDV =

```
                N
               ---
       1       \                     2
    -------     >   (PDV[n] - MeanPDV)
    (N - 1)    /
               ---
             n = 1
```

We define the skewness of PDV as follows:
Type-P-One-way-pdv-refmin-Skewness = SkewPDV =

```
                     N
                    ---                         3
                    \     /                   \
                     >   |  PDV[n]- MeanPDV   |
                    /     \                  /
                    ---
                  n = 1
            -----------------------------------
                    /                          \
                  |                  ( 3/2 )   |
                    \ (N - 1) * VarPDV         /
```

(see Appendix X of [Y.1541] (ITU-T Recommendation Y.1541, “Network Performance Objectives for IP-based Services,” February 2006.) for additional background information).
We define the Quantile of the PDVRefMin sample as the value where the specified fraction of singletons is less than the given value.

6.1.5. Composition Functions:

TOC

This section gives two alternative composition functions. The objective is to estimate a quantile of the complete path delay variation distribution. The composed quantile will be estimated using information from the sub-path delay variation distributions.

6.1.5.1. Approximate Convolution

TOC

The Type-P-Finite-One-way-Delay-<Sample>-Stream samples from each sub-path are summarized as a histogram with 1 ms bins representing the one-way delay distribution.
From [Stats] (McGraw-Hill NY NY, “Introduction to the Theory of Statistics, 3rd Edition,,” 1974.), the distribution of the sum of independent random variables can be derived using the relation:
Type-P-Composite-One-way-pdv-refmin-quantile-a =

```
                         .  .
                        /  /
   P(X + Y + Z <= a) = |  | P(X <= a-y-z) * P(Y = y) * P(Z = z) dy dz
                        /  /
                       `  `
                       z  y
```

Note that dy and dz indicate partial integration above, and that y and z are the integration variables. Also, the probablility of an outcome is indicated by the symbol P(outcome).
where X, Y, and Z are random variables representing the delay variation distributions of the sub-paths of the complete path (in this case, there are three sub-paths), and a is the quantile of interest.
This relation can be used to compose a quantile of interest for the complete path from the sub-path delay distributions. The histograms with 1 ms bins are discrete approximations of the delay distributions.

6.1.5.2. Normal Power Approximation

TOC

Type-P-One-way-Composite-pdv-refmin-NPA for the complete Source to Destination path can be calculated by combining statistics of all the constituent sub-paths in the process described in [Y.1541] (ITU-T Recommendation Y.1541, “Network Performance Objectives for IP-based Services,” February 2006.) clause 8 and Appendix X.

6.1.6. Statement of Conjecture and Assumptions

TOC

The delay distribution of a sufficiently large stream of packets measured on each sub-path during the interval [T, Tf] will be sufficiently stationary and the sub-path distributions themselves are sufficiently independent, so that summary information describing the sub-path distributions can be combined to estimate the delay distribution of complete path.
It is assumed that the one-way delay distributions of the sub-paths and the complete path are continuous.

6.1.7. Justification of the Composition Function

TOC

See the common section.

6.1.8. Sources of Deviation from the Ground Truth

TOC

In addition to the common deviations, a few additional sources exist here. For one, very tight distributions with range on the order of a few milliseconds are not accurately represented by a histogram with 1 ms bins. This size was chosen assuming an implicit requirement on

accuracy: errors of a few milliseconds are acceptable when assessing a composed distribution quantile.
Also, summary statistics cannot describe the subtleties of an empirical distribution exactly, especially when the distribution is very different from a classical form. Any procedure that uses these statistics alone may incur error.

6.1.9. Specific cases where the conjecture might fail

TOC

If the delay distributions of the sub-paths are somehow correlated, then neither of these composition functions will be reliable estimators of the complete path distribution.
In practice, sub-path delay distributions with extreme outliers have increased the error of the composed metric estimate.

6.1.10. Application of Measurement Methodology

TOC

See the common section.

---

7. Security Considerations

TOC

7.1. Denial of Service Attacks

TOC

This metric requires a stream of packets sent from one host (source) to another host (destination) through intervening networks. This method could be abused for denial of service attacks directed at the destination and/or the intervening network(s).
Administrators of source, destination, and the intervening network(s) should establish bilateral or multi-lateral agreements regarding the timing, size, and frequency of collection of sample metrics. Use of this method in excess of the terms agreed between the participants may be cause for immediate rejection or discard of packets or other escalation procedures defined between the affected parties.

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7.2. User Data Confidentiality

Active use of this method generates packets for a sample, rather than taking samples based on user data, and does not threaten user data confidentiality. Passive measurement MUST restrict attention to the headers of interest. Since user payloads may be temporarily stored for length analysis, suitable precautions MUST be taken to keep this information safe and confidential. In most cases, a hashing function will produce a value suitable for payload comparisons.

7.3. Interference with the metrics

TOC

It may be possible to identify that a certain packet or stream of packets is part of a sample. With that knowledge at the destination and/or the intervening networks, it is possible to change the processing of the packets (e.g. increasing or decreasing delay) that may distort the measured performance. It may also be possible to generate additional packets that appear to be part of the sample metric. These additional packets are likely to perturb the results of the sample measurement.
To discourage the kind of interference mentioned above, packet interference checks, such as cryptographic hash, may be used.

---

8. IANA Considerations

TOC

Metrics defined in IETF are typically registered in the IANA IPPM METRICS REGISTRY as described in initial version of the registry [RFC4148] (Stephan, E., “IP Performance Metrics (IPPM) Metrics Registry,” August 2005.).
IANA is asked to register the following metrics in the IANA-IPPM-METRICS-REGISTRY-MIB:

```
ietfFiniteOneWayDelayStream OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-Finite-One-way-Delay-Stream"
   REFERENCE
      "Reference "RFCyyyy, section 4.1."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn


ietfFiniteOneWayDelayMean OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-Finite-One-way-Delay-Mean"
   REFERENCE
      "Reference "RFCyyyy, section 4.2."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfCompositeOneWayDelayMean OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-Finite-Composite-One-way-Delay-Mean"
   REFERENCE
      "Reference "RFCyyyy, section 4.2.5."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfFiniteOneWayDelayMinimum OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-Finite-One-way-Delay-Minimum"
   REFERENCE
      "Reference "RFCyyyy, section 4.3.2."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfCompositeOneWayDelayMinimum OBJECT-IDENTITY
   STATUS current
```

```
    DESCRIPTION
       "Type-P-Finite-Composite-One-way-Delay-Minimum"
    REFERENCE
       "Reference "RFCyyyy, section 4.3."
       -- RFC Ed.: replace yyyy with actual RFC number & remove this
       note
    ::= { ianaIppmMetrics nn } -- IANA assigns nn


 ietfOneWayPktLossEmpiricProb OBJECT-IDENTITY
    STATUS current
    DESCRIPTION
       "Type-P-One-way-Packet-Loss-Empirical-Probability"
    REFERENCE
       "Reference "RFCyyyy, section 5.1.4"
       -- RFC Ed.: replace yyyy with actual RFC number & remove this
       note
    ::= { ianaIppmMetrics nn } -- IANA assigns nn


 ietfCompositeOneWayPktLossEmpiricProb OBJECT-IDENTITY
    STATUS current
    DESCRIPTION
       "Type-P-Composite-One-way-Packet-Loss-Empirical-Probability"
    REFERENCE
       "Reference "RFCyyyy, section 5.1."
       -- RFC Ed.: replace yyyy with actual RFC number & remove this
       note
    ::= { ianaIppmMetrics nn } -- IANA assigns nn



 ietfOneWayPdvRefminStream OBJECT-IDENTITY
    STATUS current
    DESCRIPTION
       "Type-P-One-way-pdv-refmin-Stream"
    REFERENCE
       "Reference "RFCyyyy, section 6.1."
       -- RFC Ed.: replace yyyy with actual RFC number & remove this
       note
    ::= { ianaIppmMetrics nn } -- IANA assigns nn


 ietfOneWayPdvRefminMean OBJECT-IDENTITY
    STATUS current
    DESCRIPTION
       "Type-P-One-way-pdv-refmin-Mean"
    REFERENCE
       "Reference "RFCyyyy, section 6.1.4."
       -- RFC Ed.: replace yyyy with actual RFC number & remove this
```

```
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn


ietfOneWayPdvRefminVariance OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-One-way-pdv-refmin-Variance"
   REFERENCE
      "Reference "RFCyyyy, section 6.1.4."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfOneWayPdvRefminSkewness OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-One-way-pdv-refmin-Skewness"
   REFERENCE
      "Reference "RFCyyyy, section 6.1.4."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfCompositeOneWayPdvRefminQtil OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-Composite-One-way-pdv-refmin-quantile-a"
   REFERENCE
      "Reference "RFCyyyy, section 6.1.5.1."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn



ietfCompositeOneWayPdvRefminNPA OBJECT-IDENTITY
   STATUS current
   DESCRIPTION
      "Type-P-One-way-Composite-pdv-refmin-NPA"
   REFERENCE
      "Reference "RFCyyyy, section 6.1.5.2."
      -- RFC Ed.: replace yyyy with actual RFC number & remove this
      note
   ::= { ianaIppmMetrics nn } -- IANA assigns nn
```

9. Contributors and Acknowledgements

TOC

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10. References

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10.1. Normative References

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10.2. Informative References

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