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Framework for Metric Composition

Abstract

This memo describes a detailed framework for composing and aggregating metrics (both in time and in space) originally defined by the IP Performance Metrics (IPPM), RFC 2330, and developed by the IETF. This new framework memo describes the generic composition and aggregation mechanisms. The memo provides a basis for additional documents that implement the framework to define detailed compositions and aggregations of metrics that are useful in practice.

Status of This Memo

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1. Introduction

The IP Performance Metrics (IPPM) framework [RFC2330] describes two forms of metric composition, spatial and temporal. The text also suggests that the concepts of the analytical framework (or A-frame) would help to develop useful relationships to derive the composed metrics from real metrics. The effectiveness of composed metrics is dependent on their usefulness in analysis and applicability to practical measurement circumstances.

This memo expands on the notion of composition, and provides a detailed framework for several classes of metrics that were described in the original IPPM framework. The classes include temporal aggregation, spatial aggregation, and spatial composition.

1.1. Motivation

Network operators have deployed measurement systems to serve many purposes, including performance monitoring, maintenance support, network engineering, and reporting performance to customers. The collection of elementary measurements alone is not enough to understand a network's behaviour. In general, measurements need to be post-processed to present the most relevant information for each purpose. The first step is often a process of "composition" of single measurements or measurement sets into other forms. Composition and aggregation present several more post-processing opportunities to the network operator, and we describe the key motivations below.

1.1.1. Reducing Measurement Overhead

A network's measurement possibilities scale upward with the square of the number of nodes. But each measurement implies overhead, in terms of the storage for the results, the traffic on the network (assuming active methods), and the operation and administration of the measurement system itself. In a large network, it is impossible to perform measurements from each node to all others.

An individual network operator should be able to organize their measurement paths along the lines of physical topology, or routing areas/Autonomous Systems, and thus minimize dependencies and overlap between different measurement paths. This way, the sheer number of measurements can be reduced, as long as the operator has a set of methods to estimate performance between any particular pair of nodes when needed.

Composition and aggregation play a key role when the path of interest spans multiple networks, and where each operator conducts their own measurements. Here, the complete path performance may be estimated from measurements on the component parts.

Operators that take advantage of the composition and aggregation methods recognize that the estimates may exhibit some additional error beyond that inherent in the measurements themselves, and so they are making a trade-off to achieve reasonable measurement system overhead.

1.1.2. Measurement Re-Use

There are many different measurement users, each bringing specific requirements for the reporting timescale. Network managers and maintenance forces prefer to see results presented very rapidly, to detect problems quickly or see if their action has corrected a problem. On the other hand, network capacity planners and even network users sometimes prefer a long-term view of performance, for example to check trends. How can one set of measurements serve both needs?

The answer lies in temporal aggregation, where the short-term measurements needed by the operations community are combined to estimate a longer-term result for others. Also, problems with the measurement system itself may be isolated to one or more of the short-term measurements, rather than possibly invalidating an entire long-term measurement if the problem was undetected.

1.1.3. Data Reduction and Consolidation

Another motivation is data reduction. Assume there is a network in which delay measurements are performed among a subset of its nodes. A network manager might ask whether there is a problem with the network delay in general. It would be desirable to obtain a single value that gives an indication of the overall network delay. Spatial aggregation methods would address this need, and can produce the desired "single figure of merit" asked for, which may also be useful in trend analysis.

The overall value would be calculated from the elementary delay measurements, but it is not obvious how: for example, it may not be reasonable to average all delay measurements, as some paths (e.g., those having a higher bandwidth or more important customers) might be considered more critical than others.

Metric composition can help to provide, from raw measurement data, some tangible, well-understood and agreed-upon information about the service guarantees provided by a network. Such information can be used in the Service Level Agreement/Service Level Specification (SLA/SLS) contracts between a service provider and its customers.

1.1.4. Implications on Measurement Design and Reporting

If a network measurement system operator anticipates needing to produce overall metrics by composition, then it is prudent to keep that requirement in mind when considering the measurement design and sampling plan. Also, certain summary statistics are more conducive to composition than others, and this figures prominently in the design of measurements and when reporting the results.

2. 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 [RFC2119].

3. Purpose and Scope

The purpose of this memo is to provide a common framework for the various classes of metrics that are composed from primary metrics. The scope is limited to the definitions of metrics that are composed from primary metrics using a deterministic function. Key information about each composed metric is included, such as the assumptions under which the relationship holds and possible sources of error/circumstances where the composition may fail.

At this time, the scope of effort is limited to composed metrics for packet loss, delay, and delay variation, as defined in [RFC2679], [RFC2680], [RFC2681], [RFC3393], [RFC5481], and the comparable metrics in [Y.1540]. Composition of packet reordering metrics [RFC4737] and duplication metrics [RFC5560] are considered research topics at the time this memo was prepared, and are beyond the scope of this document.

This memo will retain the terminology of the IPPM Framework [RFC2330] as much as possible, but will extend the terminology when necessary. It is assumed that the reader is familiar with the concepts introduced in [RFC2330], as they will not be repeated here.

4. Terminology

This section defines the terminology applicable to the processes of metric composition and aggregation.

4.1. Measurement Point

A measurement point is the logical or physical location where packet observations are made. The term "measurement point" is synonymous with the term "observation position" used in [RFC2330] when describing the notion of wire time. A measurement point may be at the boundary between a host and an adjacent link (physical), or it may be within a host (logical) that performs measurements where the difference between host time and wire time is understood.

4.2. Complete Path

The complete path is the actual path that a packet would follow as it travels from the packet's Source to its Destination. A complete path may span the administrative boundaries of one or more networks.

4.3. Complete Path Metric

The complete path metric is the Source-to-Destination metric that a composed metric attempts to estimate. A complete path metric represents the ground-truth for a composed metric.

4.4. Complete Time Interval

The complete time interval is comprised of two or more contiguous sub-intervals, and is the interval whose performance will be estimated through temporal aggregation.

4.5. Composed Metric

A composed metric is an estimate of an actual metric describing the performance of a path over some time interval. A composed metric is derived from other metrics by applying a deterministic process or function (e.g., a composition function). The process may use metrics that are identical to the metric being composed, or metrics that are dissimilar, or some combination of both types.

4.6. Composition Function

A composition function is a deterministic process applied to individual metrics to derive another metric (such as a composed metric).

4.7. Ground Truth

As applied here, the notion of "ground truth" is defined as the actual performance of a network path over some time interval. The ground truth is a metric on the (unavailable) packet transfer information for the desired path and time interval that a composed metric seeks to estimate.

4.8. Interval

An interval refers to a span of time.

4.9. Sub-Interval

A sub-interval is a time interval that is included in another interval.

4.10. Sub-Path

A sub-path is a portion of the complete path where at least the sub-path Source and Destination hosts are constituents of the complete path. We say that such a sub-path is "involved" in the complete path.

Since sub-paths terminate on hosts, it is important to describe how sub-paths are considered to be joined. In practice, the Source and Destination hosts may perform the function of measurement points.

If the Destination and Source hosts of two adjoining paths are co-located and the link between them would contribute negligible performance, then these hosts can be considered equivalent (even if there is no physical link between them, this is a practical concession).

If the Destination and Source hosts of two adjoining paths have a link between them that contributes to the complete path performance, then the link and hosts constitute another sub-path that is involved in the complete path, and should be characterized and included in the composed metric.

4.11. Sub-Path Metrics

A sub-path path metric is an element of the process to derive a composed metric, quantifying some aspect of the performance of a particular sub-path from its Source to Destination.

5. Description of Metric Types

This section defines the various classes of composition. There are two classes more accurately described as aggregation over time and space, and the third involves concatenation in space.

5.1. Temporal Aggregation Description

Aggregation in time is defined as the composition of metrics with the same type and scope obtained in different time instants or time windows. For example, starting from a time series of the measurements of maximum and minimum one-way delay (OWD) on a certain network path obtained over 5-minute intervals, we obtain a time series measurement with a coarser resolution (60 minutes) by taking the maximum of 12 consecutive 5-minute maxima and the minimum of 12 consecutive 5-minute minima.

The main reason for doing time aggregation is to reduce the amount of data that has to be stored, and make the visualization/spotting of regular cycles and/or growing or decreasing trends easier. Another useful application is to detect anomalies or abnormal changes in the network characteristics.

In RFC 2330, the term "temporal composition" is introduced and differs from temporal aggregation in that it refers to methodologies to predict future metrics on the basis of past observations (of the same metrics), exploiting the time correlation that certain metrics can exhibit. We do not consider this type of composition here.

5.2. Spatial Aggregation Description

Aggregation in space is defined as the combination of metrics of the same type and different scope, in order to estimate the overall performance of a larger network. This combination may involve weighing the contributions of the input metrics.

Suppose we want to compose the average one-way delay (OWD) experienced by flows traversing all the origin-destination (OD) pairs of a network (where the inputs are already metric "statistics"). Since we wish to include the effect of the traffic matrix on the result, it makes sense to weight each metric according to the traffic carried on the corresponding OD pair:

OWD_sum=f1*OWD_1+f2*OWD_2+...+fn*OWD_n

where fi=load_OD_i/total_load.

A simple average OWD across all network OD pairs would not use the traffic weighting.

Another example metric that is "aggregated in space" is the maximum edge-to-edge delay across a single network. Assume that a Service Provider wants to advertise the maximum delay that transit traffic will experience while passing through his/her network. There can be multiple edge-to-edge paths across a network, and the Service Provider chooses either to publish a list of delays (each corresponding to a specific edge-to-edge path), or publish a single maximum value. The latter approach simplifies the publication of measurement information, and may be sufficient for some purposes. Similar operations can be provided to other metrics, e.g., "maximum edge-to-edge packet loss", etc.

We suggest that space aggregation is generally useful to obtain a summary view of the behaviour of large network portions, or of coarser aggregates in general. The metric collection time instant, i.e., the metric collection time window of measured metrics, is not considered in space aggregation. We assume that either it is consistent for all the composed metrics, e.g., compose a set of average delays all referring to the same time window, or the time window of each composed metric does not affect the aggregated metric.

5.3. Spatial Composition Description

Concatenation in space is defined as the composition of metrics of same type with (ideally) different spatial scope, so that the resulting metric is representative of what the metric would be if obtained with a direct measurement over the sequence of the several spatial scopes. An example is the sum of mean OWDs of adjacent edge-to-edge networks, where the intermediate edge points are close to each other or happen to be the same. In this way, we can for example estimate OWD_AC starting from the knowledge of OWD_AB and OWD_BC. Note that there may be small gaps in measurement coverage; likewise, there may be small overlaps (e.g., the link where test equipment connects to the network).

One key difference from examples of aggregation in space is that all sub-paths contribute equally to the composed metric, independent of the traffic load present.

5.4. Help Metrics

In practice, there is often the need to compute a new metric using one or more metrics with the same spatial and time scope. For example, the metric rtt_sample_variance may be computed from two different metrics: the help metrics rtt_square_sum and the rtt_sum.

The process of using help metrics is a simple calculation and not an aggregation or a concatenation, and will not be investigated further in this memo.

5.5. Higher-Order Composition

Composed metrics might themselves be subject to further steps of composition or aggregation. An example would be the delay of a maximal path obtained through the spatial composition of several composed delays for each complete path in the maximal path (obtained through spatial composition). All requirements for first-order composition metrics apply to higher-order composition.

An example using temporal aggregation: twelve 5-minute metrics are aggregated to estimate the performance over an hour. The second step of aggregation would take 24 hourly metrics and estimate the performance over a day.

6. Requirements for Composed Metrics

The definitions for all composed metrics MUST include sections to treat the following topics.

The description of each metric will clearly state:

1. the definition (and statistic, where appropriate);

2. the composition or aggregation relationship;

3. the specific conjecture on which the relationship is based and assumptions of the statistical model of the process being measured, if any (see [RFC2330], Section 12);

4. a justification of practical utility or usefulness for analysis using the A-frame concepts;

5. one or more examples of how the conjecture could be incorrect and lead to inaccuracy;

6. the information to be reported.

For each metric, the applicable circumstances will be defined, in terms of whether the composition or aggregation:

- o 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.

- o Needs information or access that will only be available within an operator’s network, or is applicable to inter-network composition.
- o Requires precisely synchronized measurement time intervals in all component metrics, or perhaps only loosely synchronized time intervals, or has no timing requirements at all.
- o Requires assumption of component metric independence with regard to the metric being defined/composed, or other assumptions.
- o Has known sources of inaccuracy/error and identifies the sources.

6.1. Note on Intellectual Property Rights (IPR)

If one or more components of the composition process are encumbered by Intellectual Property Rights (IPR), then the resulting composed metrics may be encumbered as well. See BCP 79 [RFC3979] for IETF policies on IPR disclosure.

7. Guidelines for Defining Composed Metrics

7.1. Ground Truth: Comparison with Other IPPM Metrics

Figure 1 illustrates the process to derive a metric using spatial composition, and compares the composed metric to other IPPM metrics.

Metrics <M1, M2, M3> describe the performance of sub-paths between the Source and Destination of interest during time interval <T, Tf>. These metrics are the inputs for a composition function that produces a composed metric.

```
                          Sub-Path Metrics
                 ++  M1   ++ ++  M2   ++ ++  M3   ++
             Src ||.......|| ||.......|| ||.......|| Dst
                 ++   `.  ++ ++   |   ++ ++  .'   ++
                        `.        |       .-'
                          `-.     |     .'
                             `._..|.._.'
                          ,-'         `-.
                        ,'               `.
                        |   Composition   |
                        \     Function    '
                         `._           _,'
                            `--.....--'
                                  |
                 ++               |               ++
             Src ||...............................|| Dst
                 ++         Composed Metric       ++

                 ++       Complete Path Metric    ++
             Src ||...............................|| Dst
                 ++                               ++
                            Spatial Metric
                 ++   S1    ++   S2     ++    S3    ++
             Src ||........||.........||..........|| Dst
                 ++        ++         ++          ++
```

Figure 1: Comparison with Other IPPM Metrics

The composed metric is an estimate of an actual metric collected over the complete Source-to-Destination path. We say that the complete path metric represents the ground truth for the composed metric. In other words, composed metrics seek to minimize error with regard to the complete path metric.

Further, we observe that a spatial metric [RFC5644] collected for packets traveling over the same set of sub-paths provides a basis for the ground truth of the individual sub-path metrics. We note that mathematical operations may be necessary to isolate the performance of each sub-path.

Next, we consider multiparty metrics (as defined in [RFC5644]) and their spatial composition. Measurements to each of the receivers produce an element of the one-to-group metric. These elements can be composed from sub-path metrics, and the composed metrics can be combined to create a composed one-to-group metric. Figure 2 illustrates this process.

```
                             Sub-Path Metrics
                    ++  M1   ++ ++  M2   ++ ++  M3   ++
                Src ||.......|| ||.......|| ||.......||Rcvr1
                    ++       ++ ++‘.     ++ ++       ++
                                    ‘-.
                                     M4‘.++ ++  M5   ++
                                         || ||.......||Rcvr2
                                         ++ ++‘.     ++
                                                ‘-.
                                                 M6‘.++
                                                     ||Rcvr3
                                                     ++

                            One-to-Group Metric
                    ++        ++         ++          ++
                Src ||........||.........||..........||Rcvr1
                    ++        ++.        ++          ++
                                 ‘-.
                                    ‘-.  ++          ++
                                       ‘-||..........||Rcvr2
                                         ++.         ++
                                            ‘-.
                                               ‘-.   ++
                                                  ‘-.||Rcvr3
                                                     ++
```

Figure 2: Composition of One-to-Group Metrics

Here, sub-path metrics M1, M2, and M3 are combined using a relationship to compose the metric applicable to the Src-Rcvr1 path. Similarly, M1, M4, and M5 are used to compose the Src-Rcvr2 metric and M1, M4, and M6 compose the Src-Rcvr3 metric.

The composed one-to-group metric would list the Src-Rcvr metrics for each receiver in the group:

(Composed-Rcvr1, Composed-Rcvr2, Composed-Rcvr3)

The ground truth for this composed metric is of course an actual one-to-group metric, where a single Source packet has been measured after traversing the complete paths to the various receivers.

7.1.1. Ground Truth for Temporal Aggregation

Temporal aggregation involves measurements made over sub-intervals of the complete time interval between the same Source and Destination. Therefore, the ground truth is the metric measured over the desired interval.

7.1.2. Ground Truth for Spatial Aggregation

Spatial aggregation combines many measurements using a weighting function to provide the same emphasis as though the measurements were based on actual traffic, with inherent weights. Therefore, the ground truth is the metric measured on the actual traffic instead of the active streams that sample the performance.

7.2. Deviation from the Ground Truth

A metric composition can deviate from the ground truth for several reasons. Two main aspects are:

- o The propagation of the inaccuracies of the underlying measurements when composing the metric. As part of the composition function, errors of measurements might propagate. Where possible, this analysis should be made and included with the description of each metric.

- o A difference in scope. When concatenating many active measurement results (from two or more sub-paths) to obtain the complete path metric, the actual measured path will not be identical to the complete path. It is in general difficult to quantify this deviation with exactness, but a metric definition might identify guidelines for keeping the deviation as small as possible.

The description of the metric composition MUST include a section identifying the deviation from the ground truth.

7.3. Incomplete Information

In practice, when measurements cannot be initiated on a sub-path or during a particular measurement interval (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 result SHOULD be recorded as "undefined".

7.4. Time-Varying Metrics

The measured values of many metrics depend on time-variant factors, such as the level of network traffic on the Source-to-Destination path. Traffic levels often exhibit diurnal (or daily) variation, but a 24-hour measurement interval would obscure it. Temporal aggregation of hourly results to estimate the daily metric would have the same effect, and so the same cautions are warranted.

Some metrics are predominantly* time-invariant, such as the actual minimum one-way delay of a fixed path, and therefore temporal aggregation does not obscure the results as long as the path is stable. However, paths do vary, and sometimes on less predictable time intervals than traffic variations. (* Note: It is recognized that propagation delay on transmission facilities may have diurnal, seasonal, and even longer-term variations.)

8. Security Considerations

The security considerations that apply to any active measurement of live networks are relevant here as well. See [RFC4656] and [RFC5357].

The exchange of sub-path measurements among network providers may be a source of concern, and the information should be sufficiently anonymized to avoid revealing unnecessary operational details (e.g., the network addresses of measurement devices). However, the schema for measurement exchange is beyond the scope of this memo and likely to be covered by bilateral agreements for some time to come.

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10. References

10.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC2330] Paxson, V., Almes, G., Mahdavi, J., and M. Mathis, "Framework for IP Performance Metrics", RFC 2330, May 1998.

[RFC3979] Bradner, S., Ed., "Intellectual Property Rights in IETF Technology", BCP 79, RFC 3979, March 2005.

[RFC4656] Shalunov, S., Teitelbaum, B., Karp, A., Boote, J., and M. Zekauskas, "A One-way Active Measurement Protocol (OWAMP)", RFC 4656, September 2006.

[RFC5357] Hedayat, K., Krzanowski, R., Morton, A., Yum, K., and J. Babiarz, "A Two-Way Active Measurement Protocol (TWAMP)", RFC 5357, October 2008.

10.2. Informative References

[RFC2679] Almes, G., Kalidindi, S., and M. Zekauskas, "A One-way Delay Metric for IPPM", RFC 2679, September 1999.

[RFC2680] Almes, G., Kalidindi, S., and M. Zekauskas, "A One-way Packet Loss Metric for IPPM", RFC 2680, September 1999.

[RFC2681] Almes, G., Kalidindi, S., and M. Zekauskas, "A Round-trip Delay Metric for IPPM", RFC 2681, September 1999.

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

[RFC4737] Morton, A., Ciavattone, L., Ramachandran, G., Shalunov, S., and J. Perser, "Packet Reordering Metrics", RFC 4737, November 2006.

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

[RFC5560] Uijterwaal, H., "A One-Way Packet Duplication Metric", RFC 5560, May 2009.

[RFC5644] Stephan, E., Liang, L., and A. Morton, "IP Performance Metrics (IPPM): Spatial and Multicast", RFC 5644, October 2009.

[Y.1540] ITU-T Recommendation Y.1540, "Internet protocol data communication service - IP packet transfer and availability performance parameters", November 2007.

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