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R. Geib, Ed.
Deutsche Telekom
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A Connectivity Monitoring Metric for IPPM
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Abstract

Within a Segment Routing domain, segment routed measurement packets can be sent along pre-determined paths. This enables new kinds of measurements. Connectivity monitoring allows to supervise the state and performance of a connection or a (sub)path from one or a few central monitoring systems. This document specifies a suitable type-P connectivity monitoring metric.

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[1.](#) Introduction

Within a Segment Routing domain, measurement packets can be sent along pre-determined segment routed paths [[RFC8402](#)]. A segment routed path may consist of pre-determined sub paths, specific router-interfaces or a combination of both. A measurement path may also consist of sub paths spanning multiple routers, given that all segments to address a desired path are available and known at the SR domain edge interface.

A Path Monitoring System or PMS (see [[RFC8403](#)]) is a dedicated central Segment Routing (SR) domain monitoring device (as compared to a distributed monitoring approach based on router-data and -functions only). Monitoring individual sub-paths or point-to-point connections is executed for different purposes. IGP exchanges hello messages between neighbors to keep alive routing and swiftly adapt routing to topology changes. Network Operators may be interested in monitoring connectivity and congestion of interfaces or sub-paths at a timescale of seconds, minutes or hours. In both cases, the periodicity is significantly smaller than commodity interface monitoring based on router counters, which may be collected on a minute timescale to keep the processor- or monitoring data-load low.

The IPPM architecture was a first step to that direction [[RFC2330](#)]. Commodity IPPM solutions require dedicated measurement systems, a large number of measurement agents and synchronised clocks. Monitoring a domain from edge to edge by commodity IPPM solutions increases scalability of the monitoring system. But localising the site of a detected change in network behaviour may then require network tomography methods.

The IPPM Metrics for Measuring Connectivity offer generic connectivity metrics [[RFC2678](#)]. These metrics allow to measure connectivity between end nodes without making any assumption on the paths between them. The metric and the type-p packet specified by this document follow a different approach: they are designed to monitor connectivity and performance of a specific single link or a path segment. The underlying definition of connectivity is partially the same: a packet not reaching a destination indicates a loss of connectivity. An IGP re-route may indicate a loss of a link, while it might not cause loss of connectivity between end systems. The metric specified here detects a loss of connectivity, defined by a complete absence of a path between two nodes (whereas a re-routing will briefly disturb a path, but connectivity is restored by the network after a short disturbance).

A Segment Routing PMS is part of an SR domain. The PMS is IGP topology aware, covering the IP and (if present) the MPLS layer topology [[RFC8402](#)]. This allows to steer PMS measurement packets along arbitrary pre-determined concatenated sub-paths, identified by suitable Segment IDs. Basically, the SR connectivity metric as specified by this document requires set up of a number of constrained, overlaid measurement loops (or measurement paths). The delay of the packets sent along each of these measurement loops is measured. A single congested interface along a monitored sub-path adds latency along a unique subset of several measurement loops. If a monitored sub-path is no longer provides IP/MPLS connectivity between two nodes, another unique subset of measurement loops will drop all traffic while connectivity is lost. The number of measurement loops may be limited to one per sub-path (or connection) to be monitored, if a hub-and-spoke like sub-path topology as described below is monitored. In addition to information revealed by a commodity ICMP ping measurement, the metrics and methods specified here identify the location of a congested interface. To do so, tomography assumptions and methods are combined to first plan the overlaid SR measurement loop set up and later on to evaluate the captured performance metrics.

There's another difference as compared with commodity ping: the measurement loop packets remain in the data plane of passed routers. These need to forward the measurement packets without additional processing apart from that.

It is recommended to consider automated measurement loop set-ups. The methods proposed here are error-prone if the topology and measurement loop design isn't followed properly. While details of an automated set-up are not within scope of this document, some formal definitions of constraints to be respected are given.

This document specifies type-p metrics determining properties of an SR path which allows to monitor connectivity and congestion of interfaces and further allows to locate the path or interface which caused a change in the reported type-p metrics. This document is limited to the Segment Routing MPLS layer, but the methodology may be applied within SR domains or MPLS domains in general.

1.1. 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](#)].

2. A brief segment routing connectivity monitoring framework

The Segment Routing IGP topology information consists of the IP and (if present) the MPLS layer topology. The minimum SR topology information consists of Node-Segment-Identifiers (Node-SID), identifying an SR router. The IGP exchange of Adjacency-SIDs [[RFC8667](#)], which identify local interfaces to adjacent nodes, is optional. It is RECOMMENDED to distribute Adj-SIDs in a domain operating a PMS to monitor connectivity as specified below. If Adj-SIDs aren't available, [[RFC8287](#)] provides methods how to steer packets along desired paths by the proper choice of an MPLS Echo-request IP-destination address. A detailed description of [[RFC8287](#)] methods as a replacement of Adj-SIDs is out of scope of this document. Monitoring interfaces connecting nodes requires Adj-SIDs, if re-converged IP/MPLS layer connectivity would result in re-routing packets (and maintaining IP/MPLS layer connectivity) using Node-SIDs.

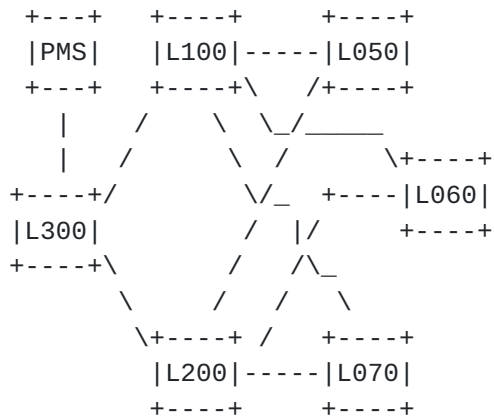
An active round trip measurement between two adjacent nodes is a simple method to monitor connectivity of a connecting link. If multiple links are operational between two adjacent nodes and only a single one fails, a single plain round trip measurement may fail to notice that or identify which link has failed. A round trip measurement also fails to identify which interface is congested, even if only a single link connects two adjacent nodes.

Segment Routing enables the set-up of extended measurement loops. Several different measurement loops can be set up to form a partial overlay. If done properly, any network change impacts more than a single measurement loop's round trip delay (or causes drops of packets of more than one loop). Randomly chosen measurement loop paths including the interfaces or paths to be monitored may fail to produce the desired unique result patterns, hence commodity network tomography methods aren't applicable [[CommodityTomography](#)]. The approach pursued here uses a pre-specified measurement loop overlay design.

A centralised monitoring approach doesn't require report collection and result correlation from two (or more) receivers (the metrics captured along different measurement loops still need to be correlated).

An additional property of the measurement loop set-up specified below is that it allows to estimate the packet round trip delay of a monitored sub-path. The delay along a single link is not perfectly symmetric. Packet processing causes small delay differences per interface and direction. These cause an error, which can't be quantified or removed by the specified method. Quantifying this error requires a different measurement set-up. As this will introduce additional measurement loops, packets and evaluations, the cost in terms of reduced scalability is not felt to be worth the benefit in terms of measurement accuracy. IPPM metrics prefer precision over accuracy and the mentioned processing differences are relatively stable, resulting in relatively precise delay estimates for each monitored sub-path.

An example hub and spoke network, operated as SR domain, is shown below. The included PMS shown is supposed to monitor the connectivity of all the 6 links (a link is a simple and generic kind of sub-path) attaching the spoke-nodes L050, L060 and L070 to the hub-nodes L100 and L200.



Hub and spoke link connectivity verification with a PMS

Figure 1

The SID values are picked for convenient reading only. Node-SID: 100 identifies L100, Node-SID: 300 identifies L300 and so on. Adj-SID 10050: Adjacency L100 to L050, Adj-SID 10060: Adjacency L100 to L060,

Adj-SID 60200: Adjacency L60 to L200 and so on (note that the Adj-SID are locally assigned per node interface, meaning two per link).

Monitoring the 6 links between hub nodes Ln00 (where n=1,2) and spoke nodes L0m0 (where m=5,6,7) requires 6 measurement loops, which have the following properties:

- o Each measurement loop follows a single round trip from one hub Ln00 to one spoke L0m0 (e.g., between L100 and L050).
- o Each measurement loop passes two more links: one between the same hub Ln00 and another spoke L0m0 and from there to the alternate hub Ln00 (e.g., from L100 to L060 and then from L060 to L200)
- o Every monitored link is passed by a single round trip measurement loop only once and further only once unidirectional by two other loops. These unidirectional measurement loop sections forward packets in opposing direction along the monitored link. In the end, three measurement loops pass each single monitored link (sub-path). In figure 1, e.g. the link between L100 and L050 is passed by one measurement loop following a round trip L100 to L050 (the measured delay is M1, see below), a second loop passes in direction L100 to L050 only (delay M3) and a third loop passes in direction L050 to L100 only (delay M6).

Note that any 6 links connecting two to five nodes can be monitored that way too. Further note that the measurement loop overlay chosen is optimised for 6 links and a hub and spoke topology of two to five nodes. The 'one measurement loop per measured sub-path' paradigm only works under these conditions.

The above overlay scheme results in 6 measurement loops for the given example. The start and end of each measurement loop is PMS to L300 to L100 or L200 and a similar sub-path on the return leg. These parts of the measurement loops are omitted here for brevity (some discussion may be found below). The following delays are measured along the SR paths of each measurement loop:

1. M1 is the delay along L100 -> L050 -> L100 -> L060 -> L200
2. M2 is the delay along L100 -> L060 -> L100 -> L070 -> L200
3. M3 is the delay along L100 -> L070 -> L100 -> L050 -> L200
4. M4 is the delay along L200 -> L050 -> L200 -> L060 -> L100
5. M5 is the delay along L200 -> L060 -> L200 -> L070 -> L100

6. M6 is the delay along L200 -> L070 -> L200 -> L050 -> L100

For brevity, in the following delay M1 also identifies the corresponding measurement loop number 1 and so on.

An example for a stack of Adj-SID segments the loop resulting in M1 is (top to bottom): 100 | 10050 | 50100 | 10060 | 60200 | PMS. As can be seen, the Node-SIDs 100 and PMS are present at top and bottom of the segment stack. Their purpose is to transport the packet from the PMS to the start of the measurement loop at L100 and return it to the PMS from its end. When connectivity is lost, a path determined by Adj-SIDs behaves deterministic: packets forwarded to the Adj-SID without connectivity are dropped.

An example for a stack of a loop consisting of Node-SID segments allowing to capture M1 is (top to bottom): 100 | 050 | 100 | 060 | 200 | PMS.

The evaluation of the measurement loop Round Trip Delays M1 - M6 allows to detect the following state-changes of the monitored sub-paths:

- o If the loops are set up using Node-SIDs only, any single complete loss of connectivity caused by a failing single link between any Ln00 and any L0m0 node briefly disturbs (and changes the measured delay) of three loops. The traffic to the Node-SIDs is re-routed (in the case of a single link loss, no node is completely disconnected in the example network). In that case, a suitable metric characterising re-routing coupled with the loss of that single link is required. The change in propagation delay might be an approach for such a metric (if any, as that depends on the resulting alternate route performance characteristics). A delay based connectivity scheme may not work under all circumstances.
- o If the measurement loops are set up using Adj-SIDs only, a loss of connectivity caused by a failing single link between any Ln00 and any L0m0 node terminates the traffic along three measurement loops. The packets of all three loops will be dropped, until the link gets back into service. Traffic to Adj-SIDs is not rerouted. Note that Node-SIDs may be used to forward the measurement packets from the PMS to the hub node, where the first sub-path to be monitored begins and from the hub node, receiving the measurement from the last monitored sub path, to the PMS.
- o The simple example only indicates superiority of Adj-SIDs over Node-SIDs only if links are monitored and the network architecture is similar to the one shown in the figure. The generic advice

is, that unambiguous connectivity monitoring is best based on packet loss, rather than on delay changes.

- o A single congested interface between any L_n00 and any L_m00 node only impacts the measured delay of two measurement loops.
- o As an example, the formula to calculate the (sub-path) Round Trip Delay (RTD) for link $L100-L050$ is shown here 4 *
$$RTD_{L100-L050-L100} = 3 * M1 + M3 + M6 - M2 - M4 - M5.$$
 This formula is reproducible for all other links: sum up 3*RTD measured along the loop passing the monitored link of interest in round trip fashion, and add the RTDs of the two measurement loops passing the link of interest only in a single direction. From this sum subtract the RTD measured on all loops not passing the monitored link of interest to get four times the RTD of the monitored link of interest.

A closer look reveals that each single event of interest for the proposed metric, which are a loss of connectivity or a case of congestion, uniquely only impacts a unique set of measurement loops which can be determined a-priori. If, e.g., connectivity is lost between $L200$ and $L050$, measurement loops $M3$, $M4$ and $M6$ indicate packet loss (or a change of the measured delay, if this approach is preferred).

As a second example: if the interface $L070$ to $L100$ is congested, measurement loops $M3$ and $M5$ indicate a change in the measured delay. Without listing all events, all cases of single losses of connectivity or single events of congestion influence only delay measurements of a unique set of measurement loops.

The measurement loops are best set up while there's no congestion. In that case, the congestion free RTDs of all monitored links can be calculated as shown above which allows to estimate the queue-depth under congestion. A single congestion event adds queuing delay to the RTD measured of two specific measurement loops. The two measurement loops impacted allow to distinct the congested interface and an estimation of the queue-depth in terms of seconds. The per link RTD can be calculated while the network is operating without congestion, say at interval $T0$. Then as an example, assume a queue of an average depth of 20 ms to build up at interface $L200$ to $L070$ at interval $T1$. The measurement loops $M5$ and $M6$ are the only ones passing the interface in that direction. Both indicate a congestion $M5$ and $M6$ of + 20 ms during a measurement interval $T1$ with congestion on that interface, while $M1-4$ indicate unchanged delays. The location of the congested interface is determined by the combination of the two (and only two) measurement loops $M5$ and $M6$ showing an

increased delay. The average queue depth = $(M5[T1] - M5[T0] + M6[T1] - M6[T0]) / 2$.

As mentioned there's a constant delay added for each measurement loop, which is the delay of the path passed from PMS -> L100 + L200 -> PMS. Please note, that this added delay is appearing twice in the formula resulting in the monitored link delay estimate of the example network. Then it is the RTD PMS -> L100 + RTD L200 -> PMS. Both RTDs can be directly measured by two additional measurements Cor1 = RTD (PMS -> L100 -> PMS) and Cor2 = RTD (PMS -> L200 -> PMS). The monitored link RTD formula was $\text{linkRTDuncor} = 3 * Mx + My + Mz - Ms - Mt - Mu$. The correct $4 * \text{linkRTDx} = 4 * \text{linkRTDxuncor} - \text{Cor1} - \text{Cor2}$.

If the interface between PMS and L100/L200 is congested, all measurement loops M1-M6 as well as Cor1 and Cor2 will see a change. A congested interface of a monitored link doesn't impact the RTDs captured by Cor1 and Cor2.

The measurement loops may also be set up between hub nodes L100 and L200, if that's preferred and supported by the nodes. In that case, the above formulas apply without correction.

3. Topology and measurement loop set up requirements

3.1. General network topology requirements

The metric and methods specified below can be applied to monitor networks or sub-paths forming a hub and spoke topology. A single sub-path status change of type loss of connectivity or congestion can be detected. The nodes don't have to act as hubs or spokes, this terminology is only chosen to describe a topology requirement. In detail, the topology to be monitored MUST meet the following constraints:

- o The SR domain sub-paths to be monitored create a hub and spoke topology with a PMS connected to all hub nodes. The PMS may reside in a hub.
- o Exactly 6 (six) sub-paths are monitored.
- o The monitored sub-paths connect at least two and no more than 5 nodes.
- o Every spoke node MUST have at least one path to every hub node.
- o Every spoke node MUST at least be connected to one (or more) hub node(s) by two monitored sub-paths.

- o Sub-paths between spokes can't be monitored and therefore are out of scope (the overlay measurement loops can't be set up as desired).

Shared resources, like a Shared Risk Link Group (e.g., a single fiber bundle) or a shared queue passed by several logical links need to be considered during set up. Shared resources may either be desired or to be avoided. As an example, if a set of logical links share one parental scheduler queue, it is sufficient to monitor a single logical connection to monitor the state of that parental scheduler.

3.2. Sub-path Monitoring measurement loop routing requirements

The methodologies specified by this document REQUIRE a measurement loop path overlay of all path delay measurement streams F_i , i in $[1, 2...6]$ as defined in this section. In the following, a path delay measurement stream F_i is called measurement (loop) F_i for brevity.

- o Define the segment routed Sub-paths SP_i , i in $[1, 2...6]$ to be monitored. The Sub-paths SP_i SHOULD not share resources, if the operator isn't aware of the impact of the shared resources on the measurement loops F_i and the methodologies defined below. The Sub-path SP_i topology SHOULD respect the general network topology requirements as specified above.
- o Set up $i = 1, 2...6$ measurement loops F_i thus that measurement F_i passes SP_i and only SP_i bidirectional (or by a round-trip) from Hub to Spoke and back. Note that the correspondance of SP_i and F_i isn't strictly required. Measurement F_i thus however appears in all methodologies calculating a metric related to SP_i .
- o Set up the SR path per measurement loops F_j and F_k thus that SP_i is passed by exactly one other measurement loop F_j unidirectional in direction Hub to Spoke and by exactly one other measurement loop F_k unidirectional in the opposite direction (Spoke to Hub). The measurement loop $F_i \neq F_j \neq F_k$. As a description, one measurement loop F_j pass SP_i in "downstream" direction from Hub to Spoke, whereas measurement loop F_k passes SP_i in "upstream" direction from Spoke to Hub.
- o Set up each segment routed measurement loop path F_i thus that it passes SP_i bidirectional as specified above, SP_j unidirectional from Hub to Spoke and SP_k unidirectional from Spoke to Hub. The monitored Sub-path SP_i MUST NOT be equal to SP_j and MUST NOT be equal to SP_k .
- o The measurement loop set up to monitor all Sub-paths SP_i is completed, if:

0

- * Each Sub-path SP_i is passed by exactly three measurements loops F_i, F_j and F_k as specified above.
- * Each segment routed measurement loop path F_i passes exactly three concatenated Sub-paths SP_i, SP_m and SP_n as specified above (indices m and n are chosen here only to avoid misconceptions which may result from picking indices j and k already appearing before - equality of j and k with either m and n is neither excluded nor required).

3.3. Path

This document specifies sub-path monitoring within a closed domain by a controlled and pre-designed measurement loop set-up. The path traversed by the packet SHOULD be reported, as detecting data plane forwarding in line with the desired measurement loop set-up is essential for the metric to enable and verify accurate evaluation. See [RFC8287] for SR MPLS OAM and [ID.draft-ietf-6man-spring-srv6-oam] for SRv6 OAM.

4. Generic Type-P-SR-Path-Periodic-* metric

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.

4.1. Metric Name

All metrics use the Type-P convention as described in [RFC2330]. The rest of the name is unique to each metric.

4.2. Generic Metric Parameters

Refer to [section 3.2](#). Metric Parameters: Type-P-* of [RFC6673]. The following parameters are added, enhanced or removed:

Dst SHOULD be a diagnostic IP address as specified by [RFC8287] and [RFC8029], if MPLS OAM is operated to capture the metric.

F_i, where i in [1, 2...6], a selection function defining unambiguously a packet of one particular stream i forming part of the monitoring overlay measurement loop set up.

L, a packet length in bits. The packets of all Type-P-SR-Path-Delay-Periodic-Streams F_i SHOULD all be of the same length.

MLAi, a stack of Segment IDs determining a monitoring loop F_i . The Segment-IDs MUST be chosen so that a singleton type-p packet of selection function F_i passes the sub-path i to be monitored.

No support: lambda (Poisson Streams remain ffs.)

4.3. Metric Units

Refer to [section 3.4](#). Metric Units: Type-P-* of [\[RFC6673\]](#).

5. Singleton Definition for Type-P-SR-Path-Periodic-Delay

5.1. Metric Name

Type-P-SR-Path-Periodic-Delay

5.2. Metric Parameters

See section [Section 4.2](#).

5.3. Delay Metric Units

A sequence of consecutive time values. The value of a Type-P-SR-Path-Periodic-Delay is either a real number or an undefined (informally, infinite) number of seconds per singleton of each stream F_i .

5.4. Definition

[Section 3.4 of \[RFC7679\]](#) applies per singleton of each stream F_i . The additional information related to singletons of [section 4.2.4 of \[RFC3432\]](#) applies too.

5.5. Discussion

See [section 3.5 of \[RFC7679\]](#). One generalisation seems appropriate: a global satellite navigation system affords one way to achieve synchronization within usec.

5.6. Methodologies

[Section 3.6 of \[RFC7679\]](#) applies per stream F_i with one exception: at the Src host, select Src and Dst IP addresses, if IP-routing is applied, or select the proper functional IP-destination address if an [\[RFC8287\]](#) SR MPLS OAM packet format is applied. Further add the

appropriate stack of Segment IDs MLA_i determining the monitoring loop Fi and form a test packet of Type-P with these addresses and the segment stack.

5.7. Errors and Uncertainties

See [section 3.7 of \[RFC7679\]](#) and [section 4.6 of \[RFC3432\]](#).

5.8. Reporting the metric

See [section 3.8 of \[RFC7679\]](#).

6. Definition of Samples for Type-P-SR-Path-Periodic-Delay

This sections defines metric samples and metrics derived from samples.

6.1. Generic Type-P-SR-Path-Periodic-Delay-* metric

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.

6.1.1. Metric Name

Type-P-SR-Path-Periodic-Delay-*

6.1.2. Metric Parameters

Src, the IP address of a host

Dst, the IP address of a host

MLA_i , a stack of Segment IDs

T_0 , a time

T_f , a time

$incT$, a time

6.1.3. Metric Units

See section [Section 5.3](#).

6.1.4. Metric Defintion

Given T_0 and T_f and nominal inter-packet interval $incT$, those time values greater than or equal to T_0 and less than or equal to T_f are then selected. At each of the selected times in this process, we obtain one value of Type-P-SR-Path-Periodic-Delay. The value of the sample is the sequence made up of the resulting [time, delay] pairs. If there are no such pairs, the sequence is of length zero and the sample is said to be empty.

6.1.5. Discussion

See [section 4.4 of \[RFC3432\]](#).

6.1.6. Errors and uncertainties

See [section 4.6 of \[RFC3432\]](#).

6.2. Definition of Type-P-SR-Path-Periodic-Delay-Stream

The only definition required for this metric is a unique metric name.

6.2.1. Metric Name

Type-P-SR-Path-Periodic-Delay-Stream

6.3. Definition of Type-P-SR-Path-Periodic-Delay-Variation

The smallest sample Type-P-SR-Path-Periodic-Delay-Stream is one of two consecutively received values. These may be used to calculate a Segment Routed Path Delay-Variation (SRDV) singleton, defined below.

6.3.1. Metric Name

Type-P-SR-Path-Periodic-Delay-Variation

6.3.2. Methodologies

SRDV[i,j], for each sample of packets j and $j-1$ of stream F_i , $j > 1$, the delay variation between successive packets is calculated as:

$$SRDV[i,j] = Delay[i,j] - Delay[i,j-1],$$

j in $[2,3...N]$ and N the total number of packets received at Dst. If one or more of the M packets sent by Src are lost, they are ignored for the metric, as no reasonable metric value is defined here. If $N > 1$, the metric is calculated for every valid packet received and the preceding one.

6.3.3. Discussion of SRDV

Evaluation statistics of differential SRDV metric samples may help to identify issues.

6.3.4. Errors and uncertainties

See [section 2.7 of \[RFC3393\]](#).

6.4. Definition of Type-P-SR-Path-Periodic-Delay-Variation-Stream

The only definition required for this metric is a unique metric name.

6.4.1. Metric Name

Type-P-SR-Path-Periodic-Delay-Variation-Stream

6.4.2. Metric Definition

Given T0 and Tf, those time values greater than or equal to T0 and less than or equal to Tf are then selected. At each of the selected times in this process, we obtain one value of Type-P-SR-Path-Periodic-Delay. The value of the sample is the sequence made up of the resulting [time, delay-variation] pairs with time being set to the Dst timestamp of the Delay-Variation singleton, for which a valid singleton is calculated. If there are no such pairs, the sequence is of length zero and the sample is said to be empty. If N Delay singletons are captured and sampled N-1 Delay-Variation singletons are sampled during the same interval

7. Statistic Definitions for SR-Path-Periodic-*-Stream samples

Change point detection requires statistical definitions. These are provided below. The names of the statistics contain an "*" placeholder, which may be replaced by "Delay" or "Delay-Variation" [Editor note: a "Loss" metric remains tbd].

7.1. SR-Path-Periodic-*-Mean

For a type-p metric, the mean is specified by:

$$\text{SR-}^*\text{Mean} = (1/N) * \text{Sum}(\text{from } i=1 \text{ to } N, \text{value}[i])$$

o N sample size

o value sample value of a sampled [time, value] pair

7.2. SR-Path-Periodic-* -Std

For a type-p metric, the Standard-Deviation Std is specified by:

$$\text{SR-*Std} = [1/(N-1)] * \text{Sum}(\text{from } i=1 \text{ to } N, [\text{SR-*Mean} - \text{value}[i]]^2)$$

- o N sample size
- o value sample value of a sampled [time, value] pair
- o SR-*Mean sample mean of the same metric as defined above

The definition as given above requires a two-pass calculation per sample. Algorithms estimating the standard-deviation by one-pass calculation have been published and might be preferable, if metric singletons and samples aren't buffered or calculations need to be fast.

8. Sub-Path monitoring metrics derived from samples captured along the measurement loops

To produce meaningful sub-path monitoring values, the measurement loop metrics are captured during a phase with stable networking conditions. In a backbone network domain, the absence of congestion often is a sufficient condition (frequent traffic shifts due to changes in routing and traffic engineering aren't expected). This may be different in a network based on a shared medium. It may be outright difficult in networks with frequently changing traffic management- and routing-policies.

In the following, the index CS indicates a statistic captured during a measurement interval with stable routing and no congestion.

8.1. Baseline measurement

Capture a sample of delay values Type-P-SR-Path-Periodic-Delay-Stream of sample size N for each measurement loop Fi. As a rule of thumb choose N in [30, 100].

For each measurement loop Fi, calculate the following metrics characterising the monitored Sub-Paths during stable and congestion free network conditions:

- o SR-Path-Delay-MeanCSi, the mean delay captured along measurement loop Fi
- o SR-Path-Delay-StdCSi, the standard-deviation of the delay captured along measurement loop Fi

- o SR-Path-Delay-Variation-MeanCSi, the mean delay variation captured along measurement loop Fi
- o SR-Path-Delay-Variation-StdCSi, the standard-deviation of the delay variation captured along measurement loop Fi

A stable and uncongested network should produce rather constant delays, resulting in low standard-deviation values and almost zero mean delay variation. [Editors note: Add text to select the median of a small set of stream mean captures, like 5 samples captured consecutively.]

Example data was captured in a lightly loaded Gigabit network. 11 routers are passed per measurement loop. The sample size is 30 packets, more than 200 samples were captured per measurement loop. The loops are set up for a different purpose than specified here, they are picked due to a high number of passed routers. Note that SR-DV-Mean here refers to an abs(SR-DV-Mean) sample, thus small, positive, non-zero means result. The time unit is microseconds.

| Metric | Quantile | SR-D-Mean | SR-D-Std | SR-DV-Mean | SR-DV-Std |
|--------|----------|-----------|----------|------------|-----------|
| Loop1 | 95% | 34510 | 40 | 28 | 49 |
| Loop2 | 95% | 35104 | 45 | 34 | 49 |
| Loop1 | 50% | 34495 | 17 | 15 | 13 |
| Loop2 | 50% | 35088 | 15 | 14 | 12 |
| Loop1 | 5% | 34504 | 10 | 12 | 11 |
| Loop2 | 5% | 35080 | 13 | 12 | 9 |

Example baseline metrics for an 11 hop measurement loop

Figure 2

8.2. Discussion of the baseline measurement

Delay outliers may occur at any time in any communication network, and the measurement system packet processing itself may also produce some. It is fair to expect only single outliers in a stable, not congested network. It may be worth to capture several consecutive SR-Path-Periodic-*-Stream samples and compare their statistics, before picking reasonable baseline metric values. Samples showing

higher standard deviations (compare the 95% quantile values in the above figure to the 50% quantile values) may benefit from removing the maximum singleton value from the sample. This will smooth the mean and standard-deviation, and if the result then is closer to those of the majority of the samples, foster confidence in determining the baseline metrics. Depending on the preferred method of data-processing and storing, this may require capturing the sample maximum as a separate metric.

8.3. Definition of SR-Path-Sub-Path-RTD-Estimate

Within a single evaluation interval of identical Time T_0 and T_f , SR-Path-Delay-MeanCSi (from now on DMeanCSi) is the mean delay of the measurement loop passing the monitored Sub-Path SP_i by a round trip. Let's keep the index i applied above, then F_j and F_k with captured mean delays DMeanCSj and DMeanCSk pass SP_i unidirectional. Further, 3 measurement loops F_x , F_y and F_z don't pass Sub-Path at all. The corresponding mean delays are DMeanCSs, DMeanCSt and DMeanCSu.

The the SR-Path-Sub-Path-RTD-Estimate of the Round Trip Delay along the monitored Sub-Path Fi , RTD_{Fi} , is

$$RTD_{Fi} = (3 * DMeanCSi + DMeanCSj + DMeanCSk - DMeanCSx - DMeanCSy - DMeanCSz) / 4$$

8.4. Definition of SR-Path-Sub-Path-* -Changepoint

The asterisk stands for "Interface" as well as "Connectivity". If connectivity is lost and no path is available between two nodes, any packets to be transmitted will be dropped. A change in sub-path routes with a change in measurement loop delay indicates a re-routing event (a temporal loss in connectivity), not a long lasting loss of connectivity. Hence a change in measurement loop delays caused by a re-routed monitored sub isn't useful to derive a metric indicating connectivity loss on a monitored sub path (a sub-path-route-change metric might be of interest, but isn't within scope of this document).

Network changes like congestion or re-routing are often characterised by a change in the mean delay of a monitoring measurement. CUSUM (cumulative sum) charts have been shown to be efficient in detecting shifts in the mean of a process [NIST]. The upper bound CUSUM is defined as:

$$Sup(t) - Fi - Delay = \max(0, Sup(t-1) + x_t - SR-Path-* - MeanCSi - k_i)$$

with $Sh_0 = 0$, $k_i = \Delta * SR-Path-* - StdCSi$ (Δ is a dimensionless integer number), $x_t = Type-P-SR-Path-Periodic-*$ singleton for measurement loop Fi at time t .

The actual SR-Path-Delay-Mean of Measurement Loop F_i is decided to be significantly above SR-Path- * -MeanCSi, if:

$\text{Sup}(t)\text{-Fi-Delay} > h_{\text{SP}}$, with $h_{\text{SP}} = d \cdot k_i$ (d is a dimensionless integer number).

An analogous CUSUM controls changes to a lower mean delay (which may be caused by a re-routing event):

$\text{Slo}(t)\text{-Fi-Delay} = \max(0, \text{Slo}(t-1) + \text{SR-Path-}^*\text{-MeanCSi} - x_j - k)$

The actual SR-Path-Delay-Mean of F_i is decided to be significantly below SR-Path- * -MeanCSi, if:

$\text{Slo}(t)\text{-Fi-Delay} > h_{\text{SP}}$

8.5. Discussion of SR-Path-Sub-Path- * -Changepoint

CUSUM chart based changepoint detection is sensible even to small changes in the mean. CUSUM charts offer a limited protection against single, isolated outliers. A cumulated sum only grows, if the controlled process consistently changes its mean (or standard deviation, respectively). Assuming constant physical minimum delays to characterise wireline communication networks, a change in standard deviation not affecting the mean delay doesn't seem to be caused by a change in networking conditions.

The measured delays will change once a Sub-Path route has changed, or once persistent congestion starts to fill a queue. Both indicate changes in the network. As the Sub-Pathes SP_i form an overlay with designed properties, every network change affecting a sub-path creates correlated SR-Path- * metric changes. As the correspondance of network changes to Sub-Path metrics is known a-priori, detecting correlated SR-Path- * metric changes allows to locate the change.

In the absence of packet re-routing, packet loss is characterising a loss of connectivity. Packet loss requires a time threshold when to decide that an active measurement packet was lost, and consecutive loss requires receiver awareness, that packets have been sent (this argues for the sender to be the receiver, unless both communicate fast and reliable out of band).

The preferred CUSUM parametrisation will depend on the kind of events to detected and on the outlier characteristics.

$k_i = \Delta * \text{SR-Path-}^*\text{-StdCSi}$ may be set to a value relevant high enough to exclude single outliers to trigger an alert, but low enough

to indicate persistent changes in delay. The same holds for the to be picked for d.

A broader discussion on CUSUM parametrisation may be found in literature. Networking skills are required to parametrise CUSUM, as well as to interpret the results (notably to differ re-routing from congestion).

8.6. Definition of SR-Path-Sub-Path-Congestion-Location

An interface along a single monitored Sub-Path SP_i whose queue is persistently filled adds latency to measurement loop F_i and one of the two unidirectional measurement loops F_j and F_k passing Sub-Path SP_i . F_j has been defined to pass SP_i from Hub to Spoke and F_k pass SP_i in opposite direction. Then SR-Path-Sub-Path-Congestion-Location metric for the traffic directed from "Hub to Spoke" along Sub-Path SP_i is:

$$SP_i_ConLoc_ij = Sup(t)_{SP_i_Periodic-Delay} + Sup(t)_{SP_j_Periodic-Delay}$$

And for the opposite traffic direction, from "Spoke to Hub":

$$SP_i_ConLoc_ik = Sup(t)_{SP_i_Periodic-Delay} + Sup(t)_{SP_k_Periodic-Delay}$$

Note that another 10 SR-Path-Sub-Path-Congestion-Location metrics are calculated, one per monitored Sub Path and traffic direction. The evaluation can be simplified as follows:

IF $SP_i_ConLoc_ij > h_{SP}$

AND $h_{SP} > Sup(t)_{SP_k_Periodic-Delay}$

AND $h_{SP} > Sup(t)_{SP_x_Periodic-Delay}$

AND $h_{SP} > Sup(t)_{SP_y_Periodic-Delay}$

AND $h_{SP} > Sup(t)_{SP_z_Periodic-Delay}$

Then Sub-Path SP_i faces congestion in direction "Hub to Spoke".

IF $SP_i_ConLoc_ik > h_{SP}$

AND $h_{SP} > Sup(t)_{SP_j_Periodic-Delay}$

AND $h_{SP} > Sup(t)_{SP_x_Periodic-Delay}$

AND $h_{SP} > Sup(t)_{SP_y_Periodic-Delay}$

AND $h_{SP} > \text{Sup}(t)_{SPz_Periodic-Delay}$

Then Sub-Path SP_i faces congestion in direction "Spoke to Hub".

Here, h_{SP} is a universal threshold in unit time to indicate a filling queue or a significant change in delay due to a Sub-Path reroute or another persistent change in topology (like e.g. automated Layer 1 / Layer 2 topology changes). SP_x , SP_y and SP_z don't pass

8.7. Singleton Definition for Type-P-SR-Path-Loss

Editors note: To be added based on existing loss metrics. A delay based approach indicating loss of a physical interface by detecting delay changes caused by re-routing can't be assumed to reliably cause unique delay change patterns under all circumstances (consider a shortest path routed multi-hop MPLS sub-path to be monitored rather than a link or a scenario where a bundle of 6 equivalent links is monitored connecting a single hub and spoke).

9. Discussion of Temporal Resolution

[Editor Note: requires a review..] The metric reports loss of connectivity of monitored sub-path or congestion of an interface and identifies the sub-path and the direction of traffic in the case of congestion.

The temporal resolution of the detected events depends on the spacing interval of packets transmitted per measurement path. An identical sending interval is chosen for every measurement path. As a rule of thumb, an event is reliably detected if a sample consists of at least 5 probes indicating the same underlying change in behavior. Depending on the underlying event either two or three measurement paths are impacted. At least two consecutively received measurement packets per measurement path should suffice to indicate a change. The values chosen for an operational network will have to reflect scalability constraints of a PMS measurement interface. As an example, a PMS may work reliable if no more than one measurement packet is transmitted per millisecond. Further, measurement is configured so that the measurement packets return to the sender interface. Assume always groups of 6 links to be monitored as described above by 6 measurements paths. If one packet is sent per measurement path within 500 ms, up to 498 links can be monitored with a reliable temporal resolution of roughly one second per detected event.

Note that per group measurement packet spacing, measurement loop delay difference and latency caused by congestion impact the reporting interval. If each measurement path of a single 6 link

monitoring group is addressed in consecutive milliseconds (within the 500 ms interval) and the sum of maximum physical delay of the per group measurement paths and latency possibly added by congestion is below 490 ms, the one second reports reliably capture 4 packets of two different measurement paths, if two measurement paths are congested, or 6 packets of three different measurement paths, if a link is lost.

A variety of reporting options exist, if scalability issues and network properties are respected.

10. IANA Considerations

If standardised, the metric will require an entry in the IPPM metric registry.

11. Security Considerations

This draft specifies how to use methods specified or described within [RFC8402] and [RFC8403]. It does not introduce new or additional SR features. The security considerations of both references apply here too.

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Author's Address

Ruediger Geib (editor)
Deutsche Telekom
Heinrich Hertz Str. 3-7
Darmstadt 64295
Germany

Phone: +49 6151 5812747
Email: Ruediger.Geib@telekom.de

