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Network performance measurement with periodic streams

Status of this Memo

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Abstract

This memo describes a periodic sampling method and relevant metrics for assessing the performance of IP networks. First, the memo motivates periodic sampling and addresses the question of its value as an alternative to the Poisson sampling described in RFC 2330. The benefits include applicability to active and passive measurements, simulation of constant bit rate (CBR) traffic (typical of multimedia communication, or nearly CBR, as found with voice activity detection), and several instances in which analysis can be simplified. The sampling method avoids predictability by mandating random start times and finite length tests. Following descriptions of the sampling method and sample metric parameters, measurement methods and errors are discussed. Finally, we give additional information on periodic measurements, including security considerations.

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1. Conventions used in this document

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 BCP 14, RFC 2119 [2]. Although RFC 2119 was written with protocols in mind, the key words are used in this document for similar reasons. They are used to ensure that the results of measurements from two different implementations are comparable, and to note instances in which an implementation could perturb the network.

2. Introduction

This memo describes a sampling method and performance metrics relevant to certain applications of IP networks. The original driver for this work was Quality of Service of interactive periodic streams, such as multimedia conferencing over IP, but the idea of periodic sampling and measurement has wider applicability. Interactive multimedia traffic is used as an example below to illustrate the concept.

Transmitting equally sized packets (or mostly same-size packets) through a network at regular intervals simulates a constant bit-rate (CBR), or a nearly CBR multimedia bit stream. Hereafter, these packets are called periodic streams. Cases of "mostly same-size packets" may be found in applications that have multiple coding methods (e.g. digitally coded comfort noise during silence gaps in speech).

In the following sections, a sampling methodology and metrics are presented for periodic streams. The measurement results may be used in derivative metrics such as average and maximum delays. The memo seeks to formalize periodic stream measurements to achieve comparable results between independent implementations.

2.1 Motivation

As noted in the IPPM framework RFC 2330 [3], a sample metric using regularly spaced singleton tests has some limitations when considered from a general measurement point of view: only part of the network performance spectrum is sampled. However, some applications also sample this limited performance spectrum and their performance may be of critical interest.

Periodic sampling is useful for the following reasons:

- * It is applicable to passive measurement, as well as active measurement.
- * An active measurement can be configured to match the characteristics of media flows, and simplifies the estimation of application performance.
- * Measurements of many network impairments (e.g., delay variation, consecutive loss, reordering) are sensitive to the sampling frequency. When the impairments themselves are time-varying (and the variations are somewhat rare, yet important), a constant sampling frequency simplifies analysis.

- * Frequency Domain analysis is simplified when the samples are equally spaced.

Simulation of CBR flows with periodic streams encourages dense sampling of network performance, since typical multimedia flows have 10 to 100 packets in each second. Dense sampling permits the characterization of network phenomena with short duration.

3. Periodic Sampling Methodology

The Framework RFC [3] points out the following potential problems with Periodic Sampling:

1. The performance sampled may be synchronized with some other periodic behavior, or the samples may be anticipated and the results manipulated. Unpredictable sampling is preferred.
2. Active measurements can cause congestion, and periodic sampling might drive congestion-aware senders into a synchronized state, producing atypical results.

Poisson sampling produces an unbiased sample for the various IP performance metrics, yet there are situations where alternative sampling methods are advantageous (as discussed under Motivation).

We can prescribe periodic sampling methods that address the problems listed above. Predictability and some forms of synchronization can be mitigated through the use of random start times and limited stream duration over a test interval. The periodic sampling parameters produce bias, and judicious selection can produce a known bias of interest. The total traffic generated by this or any sampling method should be limited to avoid adverse affects on non-test traffic (packet size, packet rate, and sample duration and frequency should all be considered).

The configuration parameters of periodic sampling are:

- + T , the beginning of a time interval where a periodic sample is desired.
- + dT , the duration of the interval for allowed sample start times.
- + T_0 , a time that MUST be selected at random from the interval $[T, T+dT]$ to start generating packets and taking measurements.
- + T_f , a time, greater than T_0 , for stopping generation of packets for a sample (T_f may be relative to T_0 if desired).
- + $incT$, the nominal duration of inter-packet interval, first bit to first bit.

T_0 may be drawn from a uniform distribution, or $T_0 = T + \text{Unif}(0, dT)$. Other distributions may also be appropriate. Start times in successive time intervals MUST use an independent value drawn from the distribution. In passive measurement, the arrival of user media flows may have sufficient randomness, or a randomized start time of the measurement during a flow may be needed to meet this requirement.

When a mix of packet sizes is desired, passive measurements usually possess the sequence and statistics of sizes in actual use, while active measurements would need to reproduce the intended distribution of sizes.

4. Sample metrics for periodic streams

The sample metric presented here is similar to the sample metric Type-P-One-way-Delay-Poisson-Stream presented in RFC 2679[4]. Singletons defined in [3] and [4] are applicable here.

4.1 Metric name

Type-P-One-way-Delay-Periodic-Stream

4.2 Metric parameters

4.2.1 Global metric parameters

These parameters apply in the following sub-sections (4.2.2, 4.2.3, and 4.2.4).

Parameters that each Singleton usually includes:

- + Src, the IP address of a host
- + Dst, the IP address of a host
- + IPV, the IP version (IPv4/IPv6) used in the measurement
- + dTloss, a time interval, the maximum waiting time for a packet before declaring it lost.
- + packet size $p(j)$, the desired number of bytes in the Type-P packet, where j is the size index.

Optional parameters:

- + PktType, any additional qualifiers (transport address)
- + Tcons, a time interval for consolidating parameters collected at the measurement points.

While a number of applications will use one packet size ($j = 1$), other applications may use packets of different sizes ($j > 1$). Especially in cases of congestion, it may be useful to use packets smaller than the maximum or predominant size of packets in the periodic stream.

A topology where Src and Dst are separate from the measurement points is assumed.

4.2.2 Parameters collected at the measurement point MP(Src)

Parameters that each Singleton usually includes:

- + Tstamp(Src)[i], for each packet [i], the time of the packet as measured at MP(Src)

Additional parameters:

- + PktID(Src) [i], for each packet [i], a unique identification or sequence number.
- + PktSi(Src) [i], for each packet [i], the actual packet size.

Some applications may use packets of different sizes, either because of application requirements or in response to IP performance experienced.

4.2.3 Parameters collected at the measurement point MP(Dst)

- + Tstamp(Dst)[i], for each packet [i], the time of the packet as measured at MP(Dst)
- + PktID(Dst) [i], for each packet [i], a unique identification or sequence number.
- + PktSi(Dst) [i], for each packet [i], the actual packet size.

Optional parameters:

- + dTstop, a time interval, used to add to time Tf to determine when to stop collecting metrics for a sample
- + PktStatus [i], for each packet [i], the status of the packet received. Possible status includes OK, packet header corrupt, packet payload corrupt, duplicate, fragment. The criteria to determine the status MUST be specified, if used.

4.2.4 Sample Metrics resulting from combining parameters at MP(Src) and MP(Dst)

Using the parameters above, a delay singleton would be calculated as follows:

- + Delay [i], for each packet [i], the time interval
$$\text{Delay}[i] = \text{Tstamp}(\text{Dst})[i] - \text{Tstamp}(\text{Src})[i]$$

For the following conditions, it will not be possible to compute delay singletons:

Spurious: There will be no Tstamp(Src)[i] time
 Not received: There will be no Tstamp (Dst) [i]
 Corrupt packet header: There will be no Tstamp (Dst) [i]
 Duplicate: Only the first non-corrupt copy of the packet received at Dst should have Delay [i] computed.

A sample metric for average delay is as follows

$$\text{AveDelay} = (1/N) \text{Sum}(\text{from } i=1 \text{ to } N, \text{ Delay}[i])$$

assuming all packets $i=1$ through N have valid singletons.

A delay variation [5] singleton can also be computed:

+ IPDV[i], for each packet [i] except the first one, delay variation between successive packets would be calculated as

$$\text{IPDV}[i] = \text{Delay}[i] - \text{Delay}[i-1]$$

IPDV[i] may be negative, zero, or positive. Delay singletons for packets i and $i-1$ must be calculable or IPDV[i] is undefined.

An example metric for the IPDV sample is the range:

$$\text{RangeIPDV} = \max(\text{IPDV}[]) - \min(\text{IPDV}[])$$

4.3 High level description of the procedure to collect a sample

Beginning on or after time T_0 , Type-P packets are generated by Src and sent to Dst until time T_f is reached with a nominal interval between the first bit of successive packets of incT , as measured at $\text{MP}(\text{Src})$. incT may be nominal due to a number of reasons: variation in packet generation at Src, clock issues (see section 4.6), etc. $\text{MP}(\text{Src})$ records the parameters above only for packets with timestamps between and including T_0 and T_f having the required Src, Dst, and any other qualifiers. $\text{MP}(\text{Dst})$ also records for packets with time stamps between T_0 and $(T_f + dT_{\text{stop}})$.

Optionally at a time $T_f + T_{\text{cons}}$ (but eventually in all cases), the data from $\text{MP}(\text{Src})$ and $\text{MP}(\text{Dst})$ are consolidated to derive the sample metric results. To prevent stopping data collection too soon, dT_{cons} should be greater than or equal to dT_{stop} . Conversely, to keep data collection reasonably efficient, dT_{stop} should be some reasonable time interval (seconds/minutes/hours), even if dT_{loss} is infinite or extremely long.

4.4 Discussion

This sampling methodology is intended to quantify the delays and the delay variation as experienced by multimedia streams of an application. Due to the definitions of these metrics, packet loss status is also recorded. The nominal interval between packets assesses network performance variations on a specific time scale.

There are a number of factors that should be taken into account when collecting a sample metric of Type-P-One-way-Delay-Periodic-Stream.

- + The interval T_0 to T_f should be specified to cover a long enough time interval to represent a reasonable use of the application under test, yet not excessively long in the same context (e.g. phone calls last longer than 100ms, but less than one week).
- + The nominal interval between packets ($incT$) and the packet size(s) ($p(j)$) should not define an equivalent bit rate that exceeds the capacity of the egress port of Src, the ingress port of Dst, or the capacity of the intervening network(s), if known. There may be exceptional cases to test the response of the application to overload conditions in the transport networks, but these cases should be strictly controlled.
- + Real delay values will be positive. Therefore, it does not make sense to report a negative value as a real delay. However, an individual zero or negative delay value might be useful as part of a stream when trying to discover a distribution of the delay errors.
- + Depending on measurement topology, delay values may be as low as 100 usec to 10 msec, whereby it may be important for Src and Dst to synchronize very closely. GPS systems afford one way to achieve synchronization to within several 10s of usec. Ordinary application of NTP may allow synchronization to within several msec, but this depends on the stability and symmetry of delay properties among the NTP agents used, and this delay is what we are trying to measure.
- + A given methodology will have to include a way to determine whether a packet was lost or whether delay is merely very large (and the packet is yet to arrive at Dst). The global metric parameter dT_{loss} defines a time interval such that delays larger than dT_{loss} are interpreted as losses. {Comment: For many applications, the treatment of a large delay as infinite/loss will be inconsequential. A TCP data packet, for example, that arrives only after several multiples of the usual RTT may as well have been lost.}

4.5 Additional Methodology Aspects

As with other Type-P-* metrics, the detailed methodology will depend on the Type-P (e.g., protocol number, UDP/TCP port number, size, precedence).

4.6 Errors and uncertainties

The description of any specific measurement method should include an accounting and analysis of various sources of error or uncertainty. The Framework RFC [3] provides general guidance on this point, but we note here the following specifics related to periodic streams and delay metrics:

- + Error due to variation of $incT$. The reasons for this can be uneven process scheduling, possibly due to CPU load.
- + Errors or uncertainties due to uncertainties in the clocks of the $MP(Src)$ and $MP(Dst)$ measurement points.
- + Errors or uncertainties due to the difference between 'wire time' and 'host time'.

4.6.1. Errors or uncertainties related to Clocks

The uncertainty in a measurement of one-way delay is related, in part, to uncertainties in the clocks of $MP(Src)$ and $MP(Dst)$. In the following, we refer to the clock used to measure when the packet was measured at $MP(Src)$ as the $MP(Src)$ clock and we refer to the clock used to measure when the packet was received at $MP(Dst)$ as the $MP(Dst)$ clock. Alluding to the notions of synchronization, accuracy, resolution, and skew, we note the following:

- + Any error in the synchronization between the $MP(Src)$ clock and the $MP(Dst)$ clock will contribute to error in the delay measurement. We say that the $MP(Src)$ clock and the $MP(Dst)$ clock have a synchronization error of T_{synch} if the $MP(Src)$ clock is T_{synch} ahead of the $MP(Dst)$ clock. Thus, if we know the value of T_{synch} exactly, we could correct for clock synchronization by adding T_{synch} to the uncorrected value of $Tstamp(Dst)[i] - Tstamp(Src)[i]$.
- + The resolution of a clock adds to uncertainty about any time measured with it. Thus, if the $MP(Src)$ clock has a resolution of 10 msec, then this adds 10 msec of uncertainty to any time value measured with it. We will denote the resolution of the source clock and the $MP(Dst)$ clock as $ResMP(Src)$ and $ResMP(Dst)$, respectively.

- + The skew of a clock is not so much an additional issue as it is a realization of the fact that T_{synch} is itself a function of time. Thus, if we attempt to measure or to bound T_{synch} , this measurement or calculation must be repeated periodically. Over some periods of time, this function can be approximated as a linear function plus some higher order terms; in these cases, one option is to use knowledge of the linear component to correct the clock. Using this correction, the residual T_{synch} is made smaller, but remains a source of uncertainty that must be accounted for. We use the function $E_{\text{synch}}(t)$ to denote an upper bound on the uncertainty in synchronization. Thus, $|T_{\text{synch}}(t)| \leq E_{\text{synch}}(t)$.

Taking these items together, we note that naive computation $T_{\text{stamp}}(\text{Dst})[i] - T_{\text{stamp}}(\text{Src})[i]$ will be off by $T_{\text{synch}}(t) \pm (\text{ResMP}(\text{Src}) + \text{ResMP}(\text{Dst}))$. Using the notion of $E_{\text{synch}}(t)$, we note that these clock-related problems introduce a total uncertainty of $E_{\text{synch}}(t) + R_{\text{source}} + R_{\text{dest}}$. This estimate of total clock-related uncertainty should be included in the error/uncertainty analysis of any measurement implementation.

4.6.2. Errors or uncertainties related to wire time vs host time

We would like to measure the time between when a packet is measured and time-stamped at $\text{MP}(\text{Src})$ and when it arrives and is time-stamped at $\text{MP}(\text{Dst})$; we refer to these as "wire times." However, if timestamps are applied by software on Src and Dst , then this software can only directly measure the time between when Src generates the packet just prior to sending the test packet and when Dst has started to process the packet after having received the test packet; we refer to these two points as "host times".

To the extent that the difference between wire time and host time is accurately known, this knowledge can be used to correct for wire time measurements. The corrected value more accurately estimates the desired (host time) metric, and visa-versa.

To the extent, however, that the difference between wire time and host time is uncertain, this uncertainty must be accounted for in an analysis of a given measurement method. We denote by H_{source} an upper bound on the uncertainty in the difference between wire time of $\text{MP}(\text{Src})$ and host time on the Src host, and similarly define H_{dest} for the difference between the host time on the Dst host and the wire time of $\text{MP}(\text{Dst})$. We then note that these problems introduce a total uncertainty of $H_{\text{source}} + H_{\text{dest}}$. This estimate of total wire-vs-host uncertainty should be included in the error/uncertainty analysis of any measurement implementation.

4.6.3. Calibration

Generally, the measured values can be decomposed as follows:

$$\text{measured value} = \text{true value} + \text{systematic error} + \text{random error}$$

If the systematic error (the constant bias in measured values) can be determined, it can be compensated for in the reported results.

$$\text{reported value} = \text{measured value} - \text{systematic error}$$

therefore

$$\text{reported value} = \text{true value} + \text{random error}$$

The goal of calibration is to determine the systematic and random error generated by the instruments themselves in as much detail as possible. At a minimum, a bound ("e") should be found such that the reported value is in the range (true value - e) to (true value + e) at least 95 percent of the time. We call "e" the calibration error for the measurements. It represents the degree to which the values produced by the measurement instrument are repeatable; that is, how closely an actual delay of 30 ms is reported as 30 ms. {Comment: 95 percent was chosen due to reasons discussed in [4], briefly summarized as (1) some confidence level is desirable to be able to remove outliers, which will be found in measuring any physical property; (2) a particular confidence level should be specified so that the results of independent implementations can be compared.}

From the discussion in the previous two sections, the error in measurements could be bounded by determining all the individual uncertainties, and adding them together to form:

$$\text{Esynch}(t) + \text{ResMP}(\text{Src}) + \text{ResMP}(\text{Dst}) + \text{Hsource} + \text{Hdest}$$

However, reasonable bounds on both the clock-related uncertainty captured by the first three terms and the host-related uncertainty captured by the last two terms should be possible by careful design techniques and calibrating the instruments using a known, isolated, network in a lab.

For example, the clock-related uncertainties are greatly reduced through the use of a GPS time source. The sum of $\text{Esynch}(t) + \text{ResMP}(\text{Src}) + \text{ResMP}(\text{Dst})$ is small, and is also bounded for the duration of the measurement because of the global time source. The host-related uncertainties, $\text{Hsource} + \text{Hdest}$, could be bounded by

connecting two instruments back-to-back with a high-speed serial link or isolated LAN segment. In this case, repeated measurements are measuring the same one-way delay.

If the test packets are small, such a network connection has a minimal delay that may be approximated by zero. The measured delay therefore contains only systematic and random error in the instrumentation. The "average value" of repeated measurements is the systematic error, and the variation is the random error. One way to compute the systematic error, and the random error, to a 95% confidence, is to repeat the experiment many times - at least hundreds of tests. The systematic error would then be the median. The random error could then be found by removing the systematic error from the measured values. The 95% confidence interval would be the range from the 2.5th percentile to the 97.5th percentile of these deviations from the true value. The calibration error "e" could then be taken to be the largest absolute value of these two numbers, plus the clock-related uncertainty. {Comment: as described, this bound is relatively loose since the uncertainties are added, and the absolute value of the largest deviation is used. As long as the resulting value is not a significant fraction of the measured values, it is a reasonable bound. If the resulting value is a significant fraction of the measured values, then more exact methods will be needed to compute the calibration error.}

Note that random error is a function of measurement load. For example, if many paths will be measured by one instrument, this might increase interrupts, process scheduling, and disk I/O (for example, recording the measurements), all of which may increase the random error in measured singletons. Therefore, in addition to minimal load measurements to find the systematic error, calibration measurements should be performed with the same measurement load that the instruments will see in the field.

We wish to reiterate that this statistical treatment refers to the calibration of the instrument; it is used to "calibrate the meter stick" and say how well the meter stick reflects reality.

4.6.4 Errors in incT

The nominal interval between packets, incT, can vary during either active or passive measurements. In passive measurement, packet headers may include a timestamp applied prior to most of the protocol stack, and the actual sending time may vary due to processor scheduling. For example, H.323 systems are required to have packets ready for the network stack within 5 ms of their ideal time. There may be additional variation from the network between the Src and the

MP(Src). Active measurement systems may encounter similar errors, but to a lesser extent. These errors must be accounted for in some types of analysis.

4.7 Reporting

The calibration and context in which the method is used MUST be carefully considered, and SHOULD always be reported along with metric results. We next present five items to consider: the Type-P of test packets, the threshold of delay equivalent to loss, error calibration, the path traversed by the test packets, and background conditions at Src, Dst, and the intervening networks during a sample. This list is not exhaustive; any additional information that could be useful in interpreting applications of the metrics should also be reported.

4.7.1. Type-P

As noted in the Framework document [3], the value of a metric may depend on the type of IP packets used to make the measurement, or "type-P". The value of Type-P-One-way-Periodic-Delay could change if the protocol (UDP or TCP), port number, size, or arrangement for special treatment (e.g., IP precedence or RSVP) changes. The exact Type-P used to make the measurements MUST be reported.

4.7.2. Threshold for delay equivalent to loss

In addition, the threshold for delay equivalent to loss (or methodology to determine this threshold) MUST be reported.

4.7.3. Calibration results

- + If the systematic error can be determined, it SHOULD be removed from the measured values.
- + You SHOULD also report the calibration error, e , such that the true value is the reported value plus or minus e , with 95% confidence (see the last section.)
- + If possible, the conditions under which a test packet with finite delay is reported as lost due to resource exhaustion on the measurement instrument SHOULD be reported.

4.7.4. Path

The path traversed by the packets SHOULD be reported, if possible. In general, it is impractical to know the precise path a given packet takes through the network. The precise path may be known for certain Type-P packets on short or stable paths. If Type-P includes the record route (or loose-source route) option in the IP header, and the

path is short enough, and all routers on the path support record (or loose-source) route, then the path will be precisely recorded.

This may be impractical because the route must be short enough. Many routers do not support (or are not configured for) record route, and use of this feature would often artificially worsen the performance observed by removing the packet from common-case processing.

However, partial information is still valuable context. For example, if a host can choose between two links (and hence two separate routes from Src to Dst), then the initial link used is valuable context. {Comment: For example, with one commercial setup, a Src on one NAP can reach a Dst on another NAP by either of several different backbone networks.}

5. Additional discussion on periodic sampling

Fig.1 illustrates measurements on multiple protocol levels that are relevant to this memo. The user's focus is on transport quality evaluation from the application point of view. However, to properly separate the quality contribution of the operating system and codec on packet voice, for example, it is beneficial to be able to measure quality at the IP level [6]. Link layer monitoring provides a way of accounting for link layer characteristics such as bit error rates.

```

-----
| application |
-----
| transport  | <--
-----
| network    | <--
-----
| link       | <--
-----
| physical   |
-----

```

Fig. 1: Different possibilities for performing measurements: a protocol view. Above, "application" refers to all layers above L4 and is not used in the OSI sense.

In general, the results of measurements may be influenced by individual application requirements/responses related to the following issues:

- + Lost packets: Applications may have varying tolerance to lost packets. Another consideration is the distribution of lost packets (i.e. random or bursty).

- + Long delays: Many applications will consider packets delayed longer than a certain value to be equivalent to lost packets (i.e. real time applications).
- + Duplicate packets: Some applications may be perturbed if duplicate packets are received.
- + Reordering: Some applications may be perturbed if packets arrive out of sequence. This may be in addition to the possibility of exceeding the "long" delay threshold as a result of being out of sequence.
- + Corrupt packet header: Most applications will probably treat a packet with a corrupt header as equivalent to a lost packet.
- + Corrupt packet payload: Some applications (e.g. digital voice codecs) may accept corrupt packet payload. In some cases, the packet payload may contain application specific forward error correction (FEC) that can compensate for some level of corruption.
- + Spurious packet: Dst may receive spurious packets (i.e. packets that are not sent by the Src as part of the metric). Many applications may be perturbed by spurious packets.

Depending, e.g., on the observed protocol level, some issues listed above may be indistinguishable from others by the application, it may be important to preserve the distinction for the operators of Src, Dst, and/or the intermediate network(s).

5.1 Measurement applications

This sampling method provides a way to perform measurements irrespective of the possible QoS mechanisms utilized in the IP network. As an example, for a QoS mechanism without hard guarantees, measurements may be used to ascertain that the "best" class gets the service that has been promised for the traffic class in question. Moreover, an operator could study the quality of a cheap, low-guarantee service implemented using possible slack bandwidth in other classes. Such measurements could be made either in studying the feasibility of a new service, or on a regular basis.

IP delivery service measurements have been discussed within the International Telecommunications Union (ITU). A framework for IP service level measurements (with references to the framework for IP performance [3]) that is intended to be suitable for service planning has been approved as I.380 [7]. ITU-T Recommendation I.380 covers abstract definitions of performance metrics. This memo describes a method that is useful, both for service planning and end-user testing purposes, in both active and passive measurements.

Delay measurements can be one-way [3,4], paired one-way, or round-trip [8]. Accordingly, the measurements may be performed either with synchronized or unsynchronized Src/Dst host clocks. Different possibilities are listed below.

The reference measurement setup for all measurement types is shown in Fig. 2.

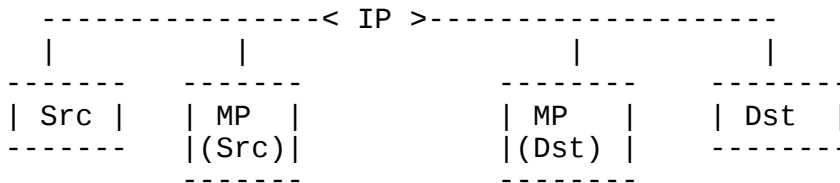


Fig. 2: Example measurement setup.

An example of the use of the method is a setup with a source host (Src), a destination host (Dst), and corresponding measurement points (MP(Src) and MP(Dst)) as shown in Figure 2. Separate equipment for measurement points may be used if having Src and/or Dst conduct the measurement may significantly affect the delay performance to be measured. MP(Src) should be placed/measured close to the egress point of packets from Src. MP(Dst) should be placed/measure close to the ingress point of packets for Dst. "Close" is defined as a distance sufficiently small so that application-level performance characteristics measured (such as delay) can be expected to follow the corresponding performance characteristic between Src and Dst to an adequate accuracy. The basic principle here is that measurement results between MP(Src) and MP(Dst) should be the same as for a measurement between Src and Dst, within the general error margin target of the measurement (e.g., < 1 ms; number of lost packets is the same). If this is not possible, the difference between MP-MP measurement and Src-Dst measurement should preferably be systematic.

The test setup just described fulfills two important criteria:

- 1) The test is made with realistic stream metrics, emulating - for example - a full-duplex Voice over IP (VoIP) call.
- 2) Either one-way or round-trip characteristics may be obtained.

It is also possible to have intermediate measurement points between MP(Src) and MP(Dst), but that is beyond the scope of this document.

5.1.1 One way measurement

In the interests of specifying metrics that are as generally applicable as possible, application-level measurements based on one-way delays are used in the example metrics. The implication of application-level measurement for bi-directional applications, such as interactive multimedia conferencing, is discussed below.

Performing a single one-way measurement only yields information on network behavior in one direction. Moreover, the stream at the network transport level does not emulate accurately a full-duplex multimedia connection.

5.1.2 Paired one way measurement

Paired one way delay refers to two multimedia streams: Src to Dst and Dst to Src for the same Src and Dst. By way of example, for some applications, the delay performance of each one way path is more important than the round trip delay. This is the case for delay-limited signals such as VoIP. Possible reasons for the difference between one-way delays is different routing of streams from Src to Dst vs. Dst to Src.

For example, a paired one way measurement may show that Src to Dst has an average delay of 30ms, while Dst to Src has an average delay of 120ms. To a round trip delay measurement, this example would look like an average of 150ms delay. Without the knowledge of the asymmetry, we might miss a problem that the application at either end may have with delays averaging more than 100ms.

Moreover, paired one way delay measurement emulates a full-duplex VoIP call more accurately than a single one-way measurement only.

5.1.3 Round trip measurement

From the point of view of periodic multimedia streams, round-trip measurements have two advantages: they avoid the need of host clock synchronization and they allow for a simulation of full-duplex communication. The former aspect means that a measurement is easily performed, since no special equipment or NTP setup is needed. The latter property means that measurement streams are transmitted in both directions. Thus, the measurement provides information on quality of service as experienced by two-way applications.

The downsides of round-trip measurement are the need for more bandwidth than a one-way test and more complex accounting of packet loss. Moreover, the stream that is returning towards the original sender may be more bursty than the one on the first "leg" of the

round-trip journey. The last issue, however, means in practice that the returning stream may experience worse QoS than the out-going one, and the performance estimates thus obtained are pessimistic ones. The possibility of asymmetric routing and queuing must be taken into account during an analysis of the results.

Note that with suitable arrangements, round-trip measurements may be performed using paired one way measurements.

5.2 Statistics calculable from one sample

Some statistics may be particularly relevant to applications simulated by periodic streams, such as the range of delay values recorded during the sample.

For example, a sample metric generates 100 packets at MP(Src) with the following measurements at MP(Dst):

- + 80 packets received with delay [i] $\leq$ 20 ms
- + 8 packets received with delay [i] $>$ 20 ms
- + 5 packets received with corrupt packet headers
- + 4 packets from MP(Src) with no matching packet recorded at MP(Dst) (effectively lost)
- + 3 packets received with corrupt packet payload and delay [i] $\leq$ 20 ms
- + 2 packets that duplicate one of the 80 packets received correctly as indicated in the first item

For this example, packets are considered acceptable if they are received with less than or equal to 20ms delays and without corrupt packet headers or packet payload. In this case, the percentage of acceptable packets is $80/100 = 80\%$.

For a different application that will accept packets with corrupt packet payload and no delay bounds (so long as the packet is received), the percentage of acceptable packets is $(80+8+3)/100 = 91\%$.

5.3 Statistics calculable from multiple samples

There may be value in running multiple tests using this method to collect a "sample of samples". For example, it may be more appropriate to simulate 1,000 two-minute VoIP calls rather than a single 2,000 minute call. When considering a collection of multiple samples, issues like the interval between samples (e.g. minutes, hours), composition of samples (e.g. equal Tf-T0 duration, different

packet sizes), and network considerations (e.g. run different samples over different intervening link-host combinations) should be taken into account. For items like the interval between samples, the usage pattern for the application of interest should be considered.

When computing statistics for multiple samples, more general statistics (e.g. median, percentile, etc.) may have relevance with a larger number of packets.

5.4 Background conditions

In many cases, the results may be influenced by conditions at Src, Dst, and/or any intervening networks. Factors that may affect the results include: traffic levels and/or bursts during the sample, link and/or host failures, etc. Information about the background conditions may only be available by external means (e.g. phone calls, television) and may only become available days after samples are taken.

5.5 Considerations related to delay

For interactive multimedia sessions, end-to-end delay is an important factor. Too large a delay reduces the quality of the multimedia session as perceived by the participants. One approach for managing end-to-end delays on an Internet path involving heterogeneous link layer technologies is to use per-domain delay quotas (e.g. 50 ms for a particular IP domain). However, this scheme has clear inefficiencies, and can over-constrain the problem of achieving some end-to-end delay objective. A more flexible implementation ought to address issues like the possibility of asymmetric delays on paths, and sensitivity of an application to delay variations in a given domain. There are several alternatives as to the delay statistic one ought to use in managing end-to-end QoS. This question, although very interesting, is not within the scope of this memo and is not discussed further here.

6. Security Considerations

6.1 Denial of Service Attacks

This method generates a periodic stream of packets from one host (Src) to another host (Dst) through intervening networks. This method could be abused for denial of service attacks directed at Dst and/or the intervening network(s).

Administrators of Src, Dst, 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, discard of packets, or other escalation procedures defined between the affected parties.

6.2 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.

6.3 Interference with the metric

It may be possible to identify that a certain packet or stream of packets is part of a sample. With that knowledge at Dst 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.

7. IANA Considerations

Since this method and metric do not define a protocol or well-known values, there are no IANA considerations in this memo.

8. Normative References

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