Network Working Group
Internet Draft
expires May 1999

C.Demichelis CSELT

November 1998

Instantaneous Packet Delay Variation Metric for IPPM
<draft-ietf-ippm-ipdv-02.txt>

1. Status of this Memo

2. Abstract

This memo refers to a metric for variation in delay of packets across Internet paths. The metric is based on statistics of the difference in One-Way-Delay of consecutive packets. This particular definition of variation is called "Instantaneous Packet Delay Variation (ipdv)".

The metric is valid for measurements between two hosts both in the case that they have synchronized clocks and in the case that they are not synchronized. In the second case it allows an evaluation of the reciprocal skew. Measurements performed on both directions (Two-ways measurements) allow a better estimation of clock differences. The precision that can be obtained is evaluated.

3. Introduction

This memo takes as a reference the Draft-ietf "One-Way-Delay metric for IPPM" that it is supposed to be known. Part of the text in this memo is directly taken from that Draft.

This memo defines a metric for variation in delay of packets that flow from one host to another one through an IP path. Since the metric is related to a variation, different definitions are possible according to what the variation is measured against.

NOTE: The terminology used in this Draft will be re-visited as soon as a terminology document will be available.
So far the following is considered:

- The term Jitter is derived from the well known definition given for transmission of electrical pulses associated to a clock, and it seems to be able to describe variations with respect to an expected arrival time.
- Each entity adopted as a reference for variation measurements defines a specific metric. Each metric describes a specific aspect or effect of the behavior of the System Under Test (SUT).
- Among entities that can be adopted, as an example, it is possible to consider a reference delay for the path, a reference delay for the Src Dst pair, the Mean One-Way-Delay over a period of interest, the Delay variation that can be derived considering the difference between the actual and the expected arrival time, the difference between the delay of a packet and the last measured similar delay.

3.1. Definition

A definition of the Instantaneous Packet Delay Variation (ipdv) can be given for a pair of packets or for a packet inside a stream of packets.

For a pair of packets:

- The ipdv of a pair of IP packets, that are transmitted from the measurement point MP1 to the measurement point MP2, is the difference between the One-Way-Delay measured for the second packet and the One-Way-Delay measured for the first packet of the pair.

For a stream of packets:

- The Instantaneous Packet Delay Variation of an IP packet, inside a stream of packets, going from the measurement point MP1 to the measurement point MP2, is the difference of the One-Way-Delay of that packet and the One-Way-Delay of the preceding packet in the stream.

3.2. Motivation

A number of services that can be supported by IP are sensitive to the regular delivery of packets and can be disturbed by instantaneous variations in delay, while they are not disturbed by slow variations, that can last a relatively long time. A specific metric for quick variations is therefore desirable. Metrics that can be derived from the analysis of statistics of ipdv can also be used, for example, for buffer dimensioning, but this memo is not intended in that sense. The scope of this metric is to provide a way for measurement of the quality delivered by a path.

In addition, this type of metric is particularly robust with respect differences and variations of the clocks of the two hosts. This allow the use of the metric even if the two hosts that support the measurement points are not synchronized. In the latter case indications on reciprocal skew of the clocks can be derived from the measurement and corrections are possible. The related precision is often comparable with the one that can be achieved with synchronized clocks, being of the same order of magnitude of synchronization errors. This will be discussed below.

3.3. General Issues Regarding Time

All what is contained in the paragraph 2.2. of the Draft ippm on One-Way Delay metric (2.2. General Issues Regarding Time) applies also in this case.

In addition, it is here considered that the reciprocal skew of the two clocks can be decomposed into two parts:
* A fixed one, called in this context "skew", given, for example, by tolerances in physical dimensions of crystals.
* A variable one, called in this context "drift", given, for example, by changes in temperature or other conditions of operation.
Both of this components are part of the term "skew" as defined in the referenced Draft and in the Framework document.

NOTE: The drift of a clock, as it is above defined over a long period must have an average value that tends to zero while the period becomes large since the frequency of the clock has a finite (and little) range. In order to underline the order of magnitude of this effect,it is considered that the maximum range of drift for commercial crystals is about 50 part per million (ppm). Since it is mainly connected with variations in operating temperature (from 0 to 70 degrees Celsius), it is expected that a host will have a nearly constant temperature during its operation period, and variations in temperature, even if quick, could be less than one Celsius per second, and range in the order of

few degrees. The total range of the drift is usually related to variations from 0 to 70 Celsius. These are important points for evaluation of precision of ipdv measurements, as it will see below.

4. Structure of this memo

The metric will be defined as applicable to a stream of packets that flow from a source host to a destination host (one-way ipdv). The initial assumption is that source and destination hosts have synchronized clocks.
The definition of a singleton of one-way ipdv metric is first considered, and then a definition of samples for ipdv will be given.

Then the case of application to not synchronized hosts will be discussed, and the precision will be compared with the one of the previous case.

A bidirectional ipdv metric will be defined, as well as the methodology for error corrections. This will not be a two-ways metric, but a "paired" one-way in opposite directions. Some statistics describing the IP path's behavior will be proposed.

In the Appendix A a more detailed analysis is reported of the ipdv theory and of the characteristics of ipdv distribution.

5. A singleton definition of a One-way ipdv metric

This definition makes use of the corresponding definition of type-P-One-Way-Delay, that is supposed to be known. This section makes use of those parts of the One-Way-Delay Draft that directly apply to the

One-Way-ipdv metric, or makes direct references to that Draft.

5.1. Metric name

Type-P-One-way-ipdv

5.2. Metric parameters

+ Scr, the IP address of a host
+ Dst, the IP address of a host
+ T1, a time
+ T2, a time. It is explicitly noted that also the difference T2-T1 is a parameter of the measurement though this is already implicit, since the times T1 and T2 exactly define the time conditions in which the measurement takes place.

+ Path, the path from Src to Dst; in cases where there is only one path from Src to Dst, this optional parameter can be omitted. {Comment: the presence of path is motivated by cases such as with Merit's NetNow setup, in which a Src on one NAP can reach a Dst on another NAP by either of several different backbone networks. Generally, this optional parameter is useful only when several dif--ferent routes are possible from Src to Dst. Using the loose source route IP option is avoided since it would often artificially worsen the performance observed, and since it might not be supported along some paths.}

5.2. Metric unit

The value of a Type-P-One-way-ipdv is either a real number of seconds (positive, zero or negative) or an undefined number of seconds.

5.3. Definition

Type-P-One-way-ipdv is defined for two (consecutive) packets from Src to Dst, as the difference between the value of the type-P-One-way-delay from Src to Dst at T2 [via path] and the value of the type-P-One-Way-Delay from Src to Dst at T1 [via path]. T1 is the wire-time at which Scr sent the first bit of the first packet, and T2 is the wire-time at which Src sent the first bit of the second packet. This metric is therefore ideally derived from the One-Way-Delay metric.

NOTE: The requirement of "consecutive" packets is not essential. The measured value is anyway the difference in One-Way-Delay at the times T1 and T2, which is meaningful by itself, as long as the times T1 and T2 are such to describe the investigated characteristics. These times will be better defined later.

Therefore, for a real number ddT "The type-P-one-way-ipdv from Src to Dst at T1, T2 [via path] is ddT" means that Src sent two consecutive packets whose the first at wire-time T1 (first bit), and the second wire-time T2 (first bit) and the packets were received by Dst at wire-time dT1+T1 (last bit of the first packet), and, respectively, at wire-time dT2+T2 (last bit of the second packet), and that dT2-dT1=ddT.

"The type-P-one-way-ipdv from Src to Dst at T1,T2 [via path] is undefined" means that Src sent the first bit of a packet at T1 and the first bit of a second packet at T2 and that Dst did not receive one or both packets.

5.4. Discussion

Type-P-One-way-ipdv is a metric that makes use of the same measurement methods provided for delay metrics.

The following practical issues have to be considered:

+ Being a differential measurement, this metric is less sensitive to clock synchronization problems. This issue will be more carefully examined in section 6. of this memo. It is pointed out that, if the reciprocal clock conditions change in time, the accuracy of the measurement will depend on the time interval T2-T1 and the amount of possible errors will be discussed below.
+ A given methodology will have to include a way to determine whether a delay value is infinite or whether it is merely very large (and the packet is yet to arrive at Dst).
As noted by Mahdavi and Paxson, simple upper bounds (such as the 255 seconds theoretical upper bound on the lifetimes of IP packets [Postel: RFC 791]) could be used, but good engineering, including an understanding of packet lifetimes, will be needed in practice. {Comment: Note that, for many applications of these metrics, the harm in treating a large delay as infinite

might be zero or very small. A TCP data packet, for example, that arrives only after several multiples of the RTT may as well have been lost.}

- + Usually a path is such that if the first packet is largely delayed, it can "stop" the second packet of the pair and vary its delay. This is not a problem for the definition since is, in any case, part of the description of the path's behavior.
- + As with other 'type-P' metrics, the value of the metric may depend on such properties of the packet as protocol,(UDP or TCP) port number, size, and arrangement for special treatment (as with IP precedence or with RSVP).
- + If the packet is duplicated along the path (or paths!) so that multiple non-corrupt copies arrive at the destination, then the packet is counted as received, and the first copy to arrive determines the packet's One-Way-Delay.
- + If the packet is fragmented and if, for whatever reason, reassembly does not occur, then the packet will be deemed lost.

5.5. Methodologies

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).

Generally, for a given Type-P, the methodology would proceed as follows:

- + The need of synchronized clocks for Src and Dst will be discussed later. Here a methodology is supposed that is based on synchronized clocks.
- + At the Src host, select Src and Dst IP addresses, and form two test packets of Type-P with these addresses. Any 'padding' portion of the packet needed only to make the test packet a given size should be filled with randomized bits to avoid a situation in which the measured delay is lower than it would otherwise be due to compression techniques along the path.
- + Optionally, select a specific path and arrange for Src to send the packets to that path. {Comment: This could be done, for example, by installing a temporary host-route for Dst in Src's routing table.}
- + At the Dst host, arrange to receive the packets.

+ At the Src host, place a timestamp in the prepared first Type-P packet, and send it towards Dst [via path].
+ If the packet arrives within a reasonable period of time, take a timestamp as soon as possible upon the receipt of the packet. By subtracting the two timestamps, an estimate of One-Way-Delay can be computed.
+ Record this first delay value.
+ At the Src host, place a timestamp in the prepared second Type-P packet, and send it towards Dst [via path].
+ If the packet arrives within a reasonable period of time, take a timestamp as soon as possible upon the receipt of the packet. By subtracting the two timestamps, an estimate of One-Way-Delay can be computed.
+ By subtracting the second value of One-Way-Delay from the first value the ipdv value of the pair of packets is obtained.
+ If one or both packets fail to arrive within a reasonable period of time, the ipdv is taken to be undefined.

5.6. Errors and Uncertainties

In the singleton metric of ipdv, factors that affect the measurement are the same that can affect the One-Way-Delay measurement, even if, in this case, the influence is different.

The Framework document provides general guidance on this point, but we note here the following specifics related to delay metrics:
+ Errors/uncertainties due to uncertainties in the clocks of the Src and Dst hosts.
+ Errors/uncertainties due to the difference between 'wire time' and 'host time'.

Each of these type of errors are discussed in more detail in the next paragraphs.

5.6.1. Errors/Uncertainties related to Clocks

If, as a first approximation, the error that affects the first measurement of One-Way-Delay were the same of the one affecting the second measurement, they will cancel each other when calculating ipdv. The residual error related to clocks is the difference of the said errors that are supposed to change from the time T1, at which the first measurement is performed, to the time T2 at which the second measurement is performed. Synchronization, skew, accuracy and resolution are here considered with the following notes:

- Errors in synchronization between source and destination clocks contribute to errors in both of the delay measurements required for calculating ipdv.
- If the synchronization error affecting the One-Way-Delay measurement is Tsync, and it is a linear function of time, through the skew value "sk", at time T1 the error will be Tsync1 and at time T2 the error will be Tsync2. The ipdv measurement will be affected by the error:
  Tsync2-Tsync1 = sk x (T2 - T1)
  depending on skew and T2-T1. To minimize this error it is possible to reduce the time interval T2-T1, but this could limit the generality of the metric.
  Methods for evaluating the synchronization error will be discussed below, since they come from a statistic over a significant sample.
  If the measurement conditions do not allow to neglect the drift, supposed as linear in the interval T2-T1, and having a value of "dr" expressed in ppm / sec., the ipdv error will become:
  Tsync2-Tsync1 = sk x (T2 - T1) + [dr x (T2-T1) x (T2-T1)] / 2
  It has to be noted that the presence of drift varies the skew value in the time. The limits in which the skew can vary are anyway limited and little, so that a given drift cannot act indefinitely. Section 7 and Appendix A provide more information on this point.
- As far as accuracy and resolution are concerned, what is noted in the above referenced Draft on One-Way-Delay at section 3.7.1, applies also in this case, with the further consideration, about resolution, that in this case the uncertainty introduced is two times the one of a single delay measurement. Errors introduced by these effects are often larger than the ones introduced by the drift.

5.6.2. Errors/uncertainties related to Wire-time vs Host-time

The content of sec. 3.7.2 of the above referenced Draft applies also in this case, with the following further consideration:
The difference between Host-time and Wire-time can be in general decomposed into two components, whose one is constant and the other is variable around zero. Only the variable components will produce measu-

rement errors, while the constant one will be canceled while calculating ipdv.

6. Definitions for Samples of One-way ipdv

Starting from the definition of the singleton metric of one-way ipdv,

some ways of building a sample of such singletons are here described. In particular two "discontinuous" samples and one "continuous" sample are defined, and the last one is proposed, being the most suitable for describing the aspect of the path's behavior underlined in the motivation.
In the following, the two packets needed for a singleton measurement will be called a "pair".

6.1. "Discontinuous" definitions

A general definition can be the following:

> Given particular binding of the parameters Src, Dst, path, and Type-P, a sample of values of parameters T1 and T2 is defined. The means for defining the values of T1 is to select a beginning time T0, a final time Tf, and an average rate lambda, then define a pseudo-random Poisson arrival process of rate lambda, whose values fall between T0 and Tf. The time interval between successive values of T1 will then average 1/lambda. Another similar, but independent, pseudo-random Poisson arrival process based on T0', Tf' and lambda', will produce a series of t' values. The time interval between successive t' values will then average 1/lambda'. For each T1 value that has been obtained by the first process, it is then possible to calculate the successive T2 values as the successive T1 values plus the successive intervals of t'.
>
> The result is shown in figure 1.

This general definition is likely go give problems, if no limits are considered for the obtained values. For example, the emission time of the first packet of a pair, could fall before the emission time of the second packet of the preceding pair. Probably this could be acceptable (provided that there are means to recognize pairs -e.g.

use of sequence numbers-), but the concept itself of ipdv would be,at least, slightly changed. A way for avoiding this type of philosophical problems can be to give some rules on the values T0, Tf, lambda, T0', Tf', lambda', without changing the meaning of the metric.

```
             |<- average interval 1/lambda ->|
             |                               |
             |<- av.int. |                   |<- av.int.    |
             |1/lambda'->|                   |  1/lambda'->|
        -----|___________|___________________|_____________|________
               pair i                          pair i+1
                             Figure 1
```

As an example, it could be defined that the process of sorting the interval between pairs starts after the interval between packets in a pair is expired, obtaining the result of figure 2:

```
                          |<--- av. int.......|
..........................|     1/lambda  --->|
                          |                   |
              |<- av.int. |                   |<- av.int.    |
              |1/lambda'->|                   |  1/lambda'->|
         -----|___________|___________________|_____________|________
                pair i                          pair i+1
                              Figure 2
```

Still other problems can be envisaged with these two definitions which are described in some more detail in Appendix A.

6.2. A "continuous" definition

A way for naturally avoiding the previous problems and producing a testing environment closer to actual scenarios is to adopt the following "continuous" definition.
A continuous stream of test packets can be supposed, where the second packet of a pair is, at the same time, the first packet of the next pair. Therefore the preceding definitions become:

+ Given particular binding of the parameters Src, Dst, path, and Type-P, a sample of values of parameter T1 is defined.
  The means for defining the values of T1 is to select a beginning time T0, a final time Tf, and an average rate lambda, then define a pseudo-random Poisson arrival process of rate lambda,

whose values fall between T0 and Tf. The time interval between successive values of T1 will then average 1/lambda. From the second value on, T1 value of the pair n coincides with T2 of the pair n-1, and the first packet of pair n coincides with the second packet of the pair n-1.

For the moment, in the following, this last definition will be considered. Further refinement is required and is for further discussion.

6.3. Metric name

Type-P-One-way-ipdv-stream

6.4. Parameters

+ Src, the IP address of a host
+ Dst, the IP address of a host

+ Path, the path* from Src to Dst; in cases where there is only one path from Src to Dst, this optional parameter can be omitted
+ T0, a time
+ Tf, a time
+ lambda, a rate in reciprocal seconds

6.5. Metric Units:

A sequence of triads whose elements are:
+ T, a time
+ Ti, a time interval.
+ dT a real number or an undefined number of seconds

6.6. Definition

A pseudo-random Poisson process is defined such that it begins at or before T0, with average arrival rate lambda, and ends at or after Tf. Those time values Ti greater than or equal to T0 and less than or equal to Tf are then selected. Starting from time T, at each pair of times T(i), T(i+1)of this process a value of Type-P-One-way-ipdv is obtained. The value of the sample is the sequence made up of the resulting <time, time interval, ipdv> triad, where the time interval is given by T(i+1)-T(i). Each obtained time T(i), excluding the first and the last, is therefore at the same time the the second time of pair i and the first time of pair i+1. The result is shown in figure 3

```
              |T(i-2)    |T(i-1)             |T(i)      |T(i+1)
         -----|__________|___________________|__________|--------
                pair i-1        pair i           pair i+1
```

Figure 3

6.7. Discussion

Note first that, since a pseudo-random number sequence is employed, the sequence of times, and hence the value of the sample, is not fully specified. Pseudo-random number generators of good quality will be needed to achieve the desired qualities.

The sample is defined in terms of a Poisson process both to avoid the effects of self-synchronization and also capture a sample that is statistically as unbiased as possible. {Comment: there is, of course, no claim that real Internet traffic arrives according to a Poisson arrival process.}

6.8. Methodology

Since packets can be lost or duplicated or can arrive in a different order with respect the one of emission, in order to recognize the pairs of test packets, they should be marked with a Sequence Number or make use of any other tool suitable to the scope. For duplicated packets only the first received copy should be considered. If a packet is lost, two values of ipdv will be undefined, since each packet, in the supposed "continuous" definition, is common to two pairs.

Steps for measurement can be the following:
+ Starting from a given time T, Src generates a test packet as for a singleton metrics, inserts in the packet a Sequence Number and the transmission Time Stamp Tx,then sorts the time Ti at which the next packet has to be sent.
+ At time Ti, Src repeats the previous step, unless T(i) > Tf.
+ On reception of the first packet, or the first packet after a SN error, Dst records SN and Tx timestamp that are contained in the packet and the reception time Rx as "old values".
+ On reception of the other packets Dst verifies the SN and if it is correct, by using the "old values" and the newly received ones, a value of ipdv is computed. Then Dst records the new SN, Tx and Rx timestamps as "old values".

6.9. Errors and uncertainties

The same considerations apply that have been made about the singleton metric. An additional error can be introduced by the pseudo-random Poisson process as focused in the above referenced Draft. Further considerations will be made in section 7, and in Appendix A.

6.10 Some statistics for One-way-ipdv

Some statistics are here considered, that can provide useful information in analyzing the behavior of the packets flowing from Src to Dst

These statistics are given having in mind a practical use of them. The focus is on the instantaneous behavior of the connection, while buffer dimensioning is not in the scope of this document.
Other statistics can be defined if needed.

6.10.1. Type-P-One-way-ipdv-inverse-percentile

Given a Type-P-One-way-ipdv-Stream and a time threshold, that can be either positive or negative, the fraction of all the ipdv values in the Stream less than or equal to the threshold, if the threshold is positive, or greater or equal to the threshold if the threshold is negative.

For many real-time services that require a regular delivery of the packets, this statistics can give the amount of packets received beyond acceptable limits.

6.10.2 Type-P-One-way-ipdv-standard-deviation

Given a Type-P-One-way-ipdv-Stream, the distribution of ipdv values is considered and the Standard Deviation can be calculated as an indication of regularity of delivery. For practical purposes it can be useful to define a total standard deviation, computed over the complete set of value, and a standard deviation computed over the subset of those values that do not exceed given positive and negative thresholds. This allows a more accurate description of the performance experienced by packets. Details on the shape of the ipdv distribution are given in Appendix A.

6.10.3 Type-P-One-way-ipdv-average

This statistic should tend to a value of ZERO for a number of ipdv values that tend to infinite. The behavior of Type-P-One-way-ipdv-average, and its meaning, are issues for the next section 7.

7. Discussion on clock synchronization

This section gives some considerations about the need of having synchronized clocks at Src and Dst. These considerations are given as a basis for discussion, they require further investigation. We start from the analysis of the mean value of the ipdv distribution related to a "continuous" sample. Some more detailed calculations are presented in Appendix A.

7.1. Mean value of ipdv distribution.

If D(i) is the delay of packet "i", and ipdv(i) is the i-th value of ipdv in the distribution of a sample of "n" values, collected with the described methodology, we can write:

ipdv(1) = D1 - D0
....
ipdv(i) = D(i) - D(i-1)
....
ipdv(n) = D(n) - D(n-1)

The mean value of ipdv distribution will result in

E(ipdv) = (D(n) - D(0))/n

If an actual measurement is performed, that lasts a period of time long enough to contain a number "n" sufficiently large and, supposing synchronized clocks, such that the network conditions (traffic) allow to find a D(n) not too different from D(0), e.g. a time of n x 24 hours, E(ipdv) will tend to zero, since the difference D(n) - D(0) will remain finite and little.

7.2. Effects of a varying traffic

If the mean values of delay D are changing inside a given period of time, for example they are increasing due to an increment of traffic, we can consider, as a first approximation, the ipdv values as decomposed into two components, one being instantaneous and another one as having a constant rate dD and corresponding to the increment "per interval" of the mean value of D. The mean value of the distribution will be shifted of the value dD corresponding to the mean value of the interval between test packets. This will happen only during the monotonic variation, and is not a distortion, since it is the record of the instantaneous behavior. When the conditions will come back to the initial ones, the distribution will resume a mean value around zero. As for the case of drift, also in this case a monotonic variation cannot take place indefinitely. In Appendix A a method is given for subdividing the variation into these two components over short periods, in order to have indications on variations of traffic conditions.

7.3. Effects of synchronization errors

We refer here to the two components that can generate this type of errors that are the reciprocal "skew" and "drift" of the Src and Dst clocks. It is first of all noted that the variable component "drift"

is physically limited and its effects can be interpreted by saying that the total reciprocal skew of the two clocks can vary, ranging from a min to a max. value in the time. This type of variation takes place very slowly being mostly connected to variations in temperature.

We suppose to perform a measurement between a Src and a Dst that have a reciprocal, initial skew of "ts1" and a reciprocal drift such that, after the time T the total skew is "ts2". It is not here a limitation to consider that at the beginning of time T the two clocks indicate the same time T0.

In order to analyze the effects produced by this situation we suppose that packets are transferred, from Src to Dst, with a constant delay D In this conditions the measured ipdv should always be zero, and what is actually measured is the error.

An ipdv value is measured at the beginning of time T with two packets having an interval of Ti(1).Another ipdv value is measured at the end of T with two packets having a time interval Ti(2).

On our purposes other errors (like wire-time vs host-time) are not considered since they are not relevant in this analysis, being common to all the measurement methods.

It is then possible to calculate the values of the Tx and Rx timestamps as they are seen by the two clocks, and the related two ipdv values.

The first ipdv value will be: ipdv1 = ts1*Ti(1) + ((ts2-ts1)/T)*Ti(1)
The second ipdv value will be: ipdv2 = ts2*Ti(2) +((ts2-ts1)/T)*Ti(2)

The error is given by the effect of the skew during the time interval Ti(i) between the two packets of the pair, and a second order term due to the variation of that skew in the same interval.

If, as in the most of practical cases, the drift can be considered close to zero, then ts1 = ts2, and the error is not depending on the time at which the measurement is done. In addition, this type of error can be corrected as it is indicated in the next paragraph and discussed in Appendix A.

In any case the maximum error on an ipdv value will correspond to the effect of the maximum reciprocal skew on the maximum interval between packets.

7.4. Related precision

This means that:

1) + If the skew is constant and is = ts all the ipdv(i) values are increased by the quantity Ti(i)*ts with respect the actual value. The mean ipdv value will therefore increased of the quantity E[Ti(i)]*ts, which is measured. Also E[Ti(i)] can be measured, and should be related to lambda. That means that the skew ts can be calculated. If together with ipdv(i), also the corresponding Ti(i) are collected, for each ipdv(i) value a correcting term is avai-lable, and a sample of "corrected" c-ipdv(i) values is obtained, where c-ipdv(i) = ipdv(i) - Ti(i)*st.

2) + Considering the total skew as subdivided into a fixed part and a variable part (skew and drift),respectively, ts and + or - td, from the mean ipdv value and the mean emission interval the average skew can be derived in the period of interest (Appendix A). The preceding correction can then be applied. The maximum residual er-ror on an ipdv value is given by the difference between the actual skew at the time in which the value has been measured and the ave-rage skew, multiplied by the time interval between the packets that have generated that ipdv value. Considerations on the number of values in the sample affected by errors are reported in

Appendix A.

3) + If the duration of the measurement is such that it is possible to consider that the effect of the items at points 7.1 and 7.2, are close to zero, the mean value of the ipdv distribution will have the value of the average skew multiplied by the mean value of the emission interval, as supposed above.

4) + We observe that the displacement due to the skew does not change the shape of the distribution, and, for example the Standard Deviation remains the same. What introduces a distortion is the effect of the drift, also when the mean value of this effect is zero at the end of the measurement. The value of this distortion is limited to the effect of the total skew variation on the emission interval.

5) + In what has been said, skew and drift have been considered as reciprocal". In Appendix A it will be considered that each of the two clocks have a skew and a drift with respect a "true time", and it will be observed that the difference is negligible with respect the situation in which one of the two clocks is taken as the "true time".

8. Definition for a bidirectional ipdv metric

We now consider that the action of the skew on one direction is the same, with opposite sign, of the action on the other direction. The idea of performing at the same time two independent measurements in the two directions is suggested by this fact.

If, after a long measurement, the variable conditions of the system under test have reached the situation of a contribution close to zero to the mean value of the ipdv distribution, it is expected that only the action of the average skew has modified the measured mean value. It is therefore expected that on one direction that value is equal and opposite to the one measured in the other direction.

This fact offers the possibility of defining a theoretical reference measurement duration in the following way:

The reference duration of a bidirectional ipdv measurement between an host E and an host W is reached at time Tf such that for each time T > Tf the expression ABS(E(ipdv E-W) - E(ipdv W-E))< epsilon, where epsilon is what we can consider as zero, is always verified. This is one, but not the only method for verifying that the mean ipdv value has reached the value of the average reciprocal skew.

At this point it is possible to evaluate the reciprocal skew. This will require the knowledge of the mean value of the intervals between consecutive packets, that can be calculated over the transmitted stream, by using the collected time stamps.

A bidirectional measurement can be defined not only as twin one-way independent metrics that take place (nearly) at the same time, but also as a two-ways metric making use of packets looped back at one end. This metric, that can be object of further study/Draft, would be able to measure also the Round Trip Delay and its variations. Problems will anyway arise on the characterization of emission intervals in the backward direction. They would be produced by the combination of the original Poisson arrival process and the effect of ipdv on the forward direction. It has to be studied if this sequence of intervals is still suitable for the measurement. also other possibilities can be envisaged for obtaining a proper backward sequence and still maintain the loopback concept.

9. References

V.Paxon, G.Almes, J.Mahdavi, M.Mathis - "Framework for IP Performance Metrics", Internet Draft <draft-ietf-ippm-framework-01.txt> Feb. 1998

G.Almes, S.Kalidindi - "A One-Way-Delay Metric for IPPM", Internet Draft <draft-ietf-ippm-delay-01.txt> Nov. 1997

10. Author's Address

Carlo Demichelis <carlo.demichelis@cselt.it>
CSELT - Centro Studi E Laboratori Telecomunicazioni S.p.A
Via G. Reiss Romoli 274
10148 - TORINO
Italy
Phone +39 11 228 5057
Fax. +39 11 228 5069

APPENDIX A

This Appendix considers the scenario in which two hosts have clocks that are both not synchronized. Between the two hosts, in an independent way and at the same time in both direction an ipdv measurement is performed according the methodology that is described in the

main body of this Draft.
This hypothetical scenario is only supposed for discussing the theory and the characteristics of the ipdv metric and its results, without considering implementation issues.

A.1 - Initial positions

The two hosts will be called West (W) and East (E). The two measurements start at the same time, while the end of the measurement it is supposed to be decided by the results of the measurement itself.

At the beginning of the measurement the time declared by the West clock is T0w, the time declared by the East clock is T0e, while the true time is T0t.

The W-clock is affected by an absolute skew of skw ppm and the E-clock by an absolute skew of skw ppm.

The W-clock is affected by an absolute drift ranging from -drw ppm to +drw ppm, the E-clock by an absolute drift ranging from -dre ppm to +dre ppm.

A.2 - Evaluation of skew and drift effects

In order to evaluate the effect of the drift on this type of metric, it is necessary to consider the time in which the variation of the skew takes place. We consider the two extreme cases in which the variation takes place uniformly from the beginning to the end of the measurement and the variation takes place suddenly at a generic time along the measurement. Let TM be the measurement time.

A.2.1 - Mean ipdv value

Since the mean ipdv value, as it has been seen, is the difference of the last delay minus the first, divided by the number of considered values, we consider what, in the two cases, is measured for first and last delay.

We call trueDf the true first Delay and trueDl the true last Delay.

For the evaluation that we want to do, it is not a limitation to consider that they are equal and have a value of trueD. We also consider as time 0 the true time at which the transmission of the first packet starts from West toward East.

In case of continuous drift we define a "drift per second" as:
drpsW = 2*drw / TM   and   drpsE = 2*dre / TM
along the measurement this will bring the skew from a value of:
skWmin = skw - drw   ;   skEmin = ske - dre
to a value of
skWmax = skw + drw   ;   skEmax = ske + dre

What is measured as first Delay is:

measured first Rx time - measured first Tx time
OffsetEast + trueD*[1 + skEmin + (1/2)*drpsE] - OffsetWest

What is measured as last Delay is:

measured last Rx time - measured last Tx time
OffsetEast + (TM + trueD)*[1 + skEmin + (1/2)*2*dre] -
- OffsetWest - TM*[1 + skWmin + (1/2)*2*drw]

The difference between the last and first Delay is therefore:

TM*(skEmin - skWmin + dre - drw) - trueD*drpsE/(2*TM)

if TM = 10 hours drpsE is in the order of 50*10E-6 / 36000 that is
about 10E-9 and the second term of the expression is in the order of
10E-14 for true delays in the order of 1 sec (negligible term).
We consider that, with very good approximation:

Mean emission interval (mti) = TM / number of ipdv values (N)
Therefore:

mean ipdv = (measured last Delay - measured first Delay) / N =
= mti*(skEmin - skWmin + dre - drw)

but we considered skEmin = ske - dre and skWmin = skw - drw
and therefore:

mean ipdv = (meas.lastD - meas.firstD) / mti*(reciprocal mean skew)

The previous procedure is now applied to the case in which the total
drift takes place in a very short time. Some cases are possible, and
we consider the one in which at the beginning the West clock has
skWmax and the East clock has skEmin, at time txW the West clock
assumes skWmin and at time txE the East clock assumes skEmax.

What is measured as first Delay is now:

measured first Rx time - measured first Tx time
OffsetEast + trueD*(1 + skEmin) - OffsetWest

What is measured as last Delay is:

measured last Rx time - measured last Tx time
+ OffsetEast + txE*(1 + skEmin) + (TM - txE)*(1 + skEmax) +
+ trueD*(1 + skEmax) -
- OffsetWest - txW*(1 + skWmax) - (TM - txW)*(1 + skWmin)

but the mean skew values will be:

mskw = [skWmax*txW + skWmin*(TM - txW)] / TM
mske = [skEmin*txE + skEmax*(TM - txE)] / TM

the difference between the two delays therefore is:

TM*(mske - mskw) + 2*trueD*dre

and the mean ipdv value will be:

mean ipdv = mti*(mske - mskw) + 2*mti*trueD*dre/TM

the second term of the second member in the previous hypotheses is in the order of the nanosecond, and we neglect it. Also in this case, from the mean ipdv value, and knowing the mean emission interval, the relative skew of the clocks can be obtained.

More in general, independently on how the drift acts inside its limits, we assert that always the mean ipdv value divided by the mean emission interval produces the value of the mean reciprocal skew of the two clocks, provided that the collected number of ipdv values is significant for the statistics.

A.2.2 - Errors and corrections

If the drift is always close to zero, it is possible to obtain the true value of the reciprocal skew and correct all the ipdv values. Each of them is associated to an emission interval ti between the two packets that have produced the value itself. Then a better ipdv value will be:
corr.ipdv(i) = meas.ipdv(i) - ti * skew
This is a better value but not exactly the true one, since we supposed that both clocks are not synchronized to the true time. Two errors are affecting the corrective terms which are:

+ The reciprocal skew is measured as referred to the Src clock
+ The interval ti is measured by the Src clock.
These are second order errors since the measured skew will be affected by a "relative" error in the order of the Src skew, an the same is for the error affecting the ti value.

If the drift is significant and it can range from the lower to the upper limit of its field, the measured average of the skew will depend on the type of variation. Some cases are considered that demonstrate that actually the proposed correction is not so much effective in this case. Only the fixed part of the total clock variation can be properly corrected.

A.2.2.1 - Constant drift

The first case is the first one considered in the preceding paragraph, where the drift is uniform. We suppose that a reciprocal skew is measu--red and used for correction.

At the beginning of the measurement the actual reciprocal skew is:

init.skew = mean.skew - rel.max.drift

and at the end the actual reciprocal skew is:

final.skew = mean.skew + rel max.drift

The correction is effective only in the central part of the measurement. At the beginning and at the end a residual error will affect the ipdv values whose value will be:

ipdv(i).err = ti * rel.max.drift

We underline here that the error is larger for large intervals ti and lower for short intervals ti. For intervals derived from a poissonian arrival process, there are many short intervals and few large intervals. We also note that a constant drift cannot last indefinitely, since there is a minimum and a maximum for the skew.

A.2.2.2 - Step of drift

In this case the error profile depends on the time at which the drift changes. If the change is near the beginning or near the end of the measurement, the calculated mean skew will be very close to the actual skew of the largest part of the measurement. On that part the correction will be effective, while over the remaining few values the error will be twice with respect the preceding case.

The worse condition is produced by a change in drift in the middle of the measurement. In this case the correction would be useful only if the drift was significantly less than the skew.

A.3 - Comparison with a synchronized case

In this section we consider a case in which the two hosts have synchronized clocks, and the synchronization is obtained by setting the real time each second in each of the clocks. We optimistically suppose that this is done exactly (without any imprecision). On the clocks, anyway skew and drift continue to act. We refer to reciprocal skew and drift, having already seen that this is significant. We suppose to perform an ipdv measurement and we evaluate what is measured by the mean ipdv value and what is the error on the measured ipdv values.

We notice, first of all, that nothing changes for ipdv values measured over intervals falling completely between two synchronization instants. In this case, the effect of synchronization is only to put to zero the offset, that does not appear in the calculation of ipdv values.

Something different happens if the synchronization instant (or more synchronization instants) falls inside the interval. In this case the error can range from + to - the error related to one second interval, or, more in general, from + to - the error related to an interval equal to the synchronization period. The (few) large intervals will produce a limited error while the (many) short intervals will continue to produce errors of the same order of magnitude of the not synchronized case.

Besides, even if the drift is negligible, the mean ipdv value is no more suitable to calculate the skew, and it will be much more close to zero. Therefore it is no more possible to correct the distortion of the distribution.

Finally, it is necessary to add to these errors the unavoidable imprecision of the synchronization process. We have to consider that the magnitude of errors introduced by skew and drift is in the order of tenth of microseconds. Not always the complete synchronization process has a better precision.

A.4 - Bidirectional measurement and components of ipdv

Three terms have been described that can displace the mean ipdv value from zero. They are:

- The total skew, already discussed above, that always acts in an equal way and opposite direction over the two directions between West and East hosts.
- The effect of varying traffic that can increase or decrease along limited periods, the average value of the One-Way-Delay. The metric above presented supposes that the measurement period is large enough for considering this effect as tending to zero.
  It is explicitly noted that the effect will produce a zero effect only on the mean ipdv value, while the effect on values ipdv(i) is always present. This is not a distortion of the distribution, since is part of the variation that is measured. This effect is different, and usually concordant, on the two directions.
- The difference between first and last instantaneous values of the delay variation, that tends to zero when the number of collected ipdv values becomes large.

In order to isolate the last two effects, we consider here a measurement over a long period (e.g. 24 hours)where the drift is negligible, and the effect of the skew has been corrected.

A.4.1 - Slow variation in a given period

The packets of the stream can be represented on a system of cartesian orthogonal axes with transmission time on x-axis and reception time on y-axis, by points localized by transmission and reception time of each packet. Considering an arbitrary period of time Tper, which will be a parameter of this procedure, it can be taken as a sliding window over the sample and for each position of this window, established by successive packets, the segment of straight line is calculated that best approximate the points, by means of a linear regression method.

The slope of this segment will be one if along the period the delay has not changed, and different from one if that delay has increased (>1) or decreased (<1). For each position of the window it is therefore possible to find a value of "slow delay variation" with Tper as a parameter. This will give an indication on variations produced by different traffic conditions along the measurement period. This item can be subject for further study.

At the same time this procedure offers a criterion for reducing the error introduced in the calculation of the mean ipdv by the instantaneous component of the difference between last and first delay. Supposing that the timestamps, on which the metric is based, are collected and then processed, if the method of the sliding window is applied at the beginning and at the end of the collected sample, it is possible to avoid starting and ending the measurement on values possibly too different from the average (points too far away from the calculated straight line).

A.5 - Symmetry of an ipdv distribution and emission intervals

It is demonstrated that, if the packets of the test sequence are propagated in an independent way, in the sense that none of them is influenced by the preceding packets (large emission intervals), the ipdv distribution will be perfectly symmetrical. If the variation of the delay is such that some packets is delayed by the preceding one (ideally queued to it in a buffer), the related ipdv value generated will have a lower limit, that will be the negative value of the emission interval minus the time required for transmitting the packet from the buffer. If the intervals were constant, this would correspond to a well defined value, that would allow to measure the bandwidth of the bottleneck provided by the output of that buffer. Since the intervals are derived from a poissonian arrival process, this limit is not a fixed one, and is not immediately evident of the ipdv distribution.

Another effect of this interference among packets is that also the packet following the queued one will produce a lower ipdv value since it will "gain" the time of latency in the buffer of the previous one.

The total effect is that the ipdv values will tend to concentrate on the negative side of the distribution, with some limitation on the negative maximum values. In other words, the negative side of the distribution will be shorter than the positive one, but containing more values. Nothing changes for the meaning of the mean ipdv value.

This asymmetry is not a distortion, since represents the actual propa-

-gation characteristics. For the supposed type of intervals, the distribution is always asymmetrical, since always are present intervals lower than the delay variability, and the degree of asymmetry will change with the level of interference.

The relationship between asymmetry and the combination of average emission interval and available bandwidth can be investigated and could provide information about the level of congestion of the network