    Instantaneous Packet Delay Variation Metric for IPPM
        <draft-ietf-ippm-ipdv-01.txt>

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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
 relative skew. Measurements performed on both directions (Two-ways
 measurements) allow a better estimation of clock differences. The
 precision that can be obtained is evaluated.

 This memo is intended to have, as much as possible, the structure of
 the ippm draft on one-way delay metric.

3. Introduction

This memo refers to the Draft-ietf "One-way-delay metric for IPPM" that
supposes as 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.

3.1. Definition

 The Instantaneous Packet Delay Variation of an IP packet, inside a
 stream of packets, going from the measurement point MP1 to the measu-
 rement point MP2, is the difference of the One-Way Delay of that packet
 and the One-Way Delay of 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 va-
 riations in delay, while they are not disturbed by slow variations,
 that can last a relatively long time. A specific metric for quick va-
 riations is therefore desirable. Metrics that can be derived from the
 analysis of statistics of ipdv can also be used for buffer
 dimensioning, but this memo is not intended in that sense. The scope
 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 measure-
 ment points are not synchronized. The related precision is comparable
 with the one that can be achieved with synchronized clocks. 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 relative 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 dimension 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.

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 ini
-tial assumption is that source and destination hosts have synchronized
clocks.
The definition of a singleton of one-way ipdv metric is first consi-
dered, and then a definition of samples for ipdv will be given.

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

A bidirectional ipdv metric will be defined, and 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.

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. Gener-
   ally, this optional parameter is useful only when several different
   routes are possible from Src to Dst. Using the loose source route IP
   option is avoided since it would often artificially worsen the per-
   formance 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 unde-
fined" 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 care-
    fully examined in section 6. of this memo. It is pointed out
    that, if the reciprocal clock conditions change in time, the ac-
    curacy 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 deter-
    mine whether a delay value is infinite or whether it is mere-
    ly 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 nee-
    ded 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 de-
    pend 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, reas-
    sembly 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 fol-
 lows:

 + The need of synchronized clocks for Src and Dst will be discus-
      sed 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' por-
  tion 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 are discussed in more detail below.

5.6.1. Errors/Uncertainties related to Clocks

 If, as a first approximation, the error that affects the first measu-
 rement 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 measure-
 ment 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 is Tsync, and it is a linear func-
   tion of time, through the skew value, at time T1 the error will
   be Tsync1 and at time T2 the error will be Tsync2. The ipdv mea-
   surement will be affected by the error Tsync2-Tsync1, depending
   from skew and T2-T1. To minimize this error it is possible to
   reduce the time interval T2-T1, but this could limit the genera-
   lity of the metric. Methods for evaluating the synchronization
   error will be discussed below, since they come from a statistic

over a significant sample.
 + 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.

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 de-
 composed 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 calcu-
 lating 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
 that have to be further analyzed in order to find the best way of con-
 sidering all the related problems. In the following, the two packets
 needed for a singleton measurement will be called a "pair".

6.1. A "discontinuous" definition

 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 si-
  milar, 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
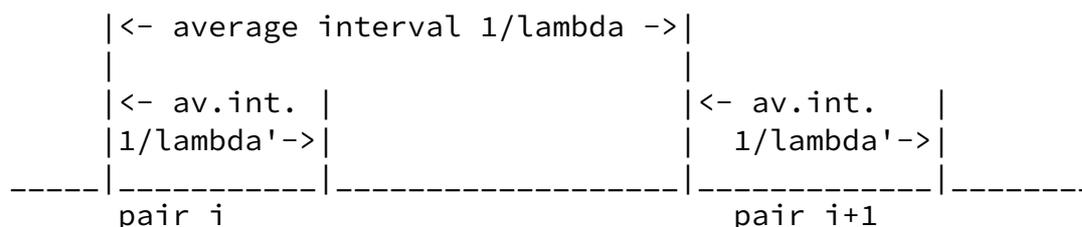successive intervals of t'.

The result is shown in figure 1.

```
      |<- average interval 1/lambda ->|
      |                               |
      |<- av.int. |                   |<- av.int.    |
      |1/lambda'->|                   |   1/lambda'->|
 _____|_____|_____|_____|_____
       pair i                          pair i+1
                  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.

6.2. A "continuous" definition

A way to naturally avoid the previous problem is to adopt the following
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 definition becomes:

 + 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 se-

cond packet of the pair n-1.
For the moment, in the following, this second definition will be con-
sidered. 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 2

```
        |T(i-2)    |T(i-1)                |T(i)       |T(i+1)
  _____|_____|_____|_____|_____
        pair i-1              pair i          pair i+1
                        Figure 2
```

[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 pac-
ket 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 single-
ton metric. An additional error can be introduced by the pseudo-ran-
dom Poisson process as focused in the above referenced Draft.
Further considerations will be made in section 7.

[6.10](#) Some statistics for One-way-ipdv

  Some statistics are here considered, that can provide useful informa-
  tion 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 ne-
  gative.

  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
  useful to define a total standard deviation, computed over the com-
  plete set of value, and a standard deviation computed over the sub-
  set of those values that do not exceed given positive and negative
  thresholds. This allows a more accurate description of the performan-
  ce experienced by packets.

[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 syn-
  chronized 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.

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.

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 decom-
 posed 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. When the conditions will come back
 to the initial ones, the distribution will resume a mean value around
 zero. At any time the distribution will correctly describe the
 effects of the path on the packet flow.

7.3. Effects of synchronization errors

We refer here to the two components that can generate this type of
errors that are the relative "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 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.

It is then possible to calculate the values of the Tx and Rx time-
stamps as they are seen by the two clocks, and the related values of
the 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 amount of variation during the time inter-
val $Ti(i)$ between the two packets of the pair, and a second order
term due to the variation of that variation in the same interval.

If, as in practical cases, the drift can be considered zero, then
ts1 = ts2, and the error is not depending on the time at which the
measurement is done.

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.

2) + Considering the total skew as subdivided into a fixed part and a
     variable part (skew and drift),respectively, ts and + or - td, and
    a minimum time T in which the drift can go from -td to +td or vice
    -versa, each ipdv(i) value will be increased of the fixed quantity
    Ti(i)*ts plus or minus, as a maximum, the quantity 2*td*Ti(i)/T

---

  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,
    and the effect of the drift are negligible (related average ten-
    ding to zero), the mean value of the ipdv distribution will have
   the value of the skew multiplied by the mean value of the emission
   interval.
  4) + We observe that the displacement due to the skew does not change
    the shape of the distribution, and, for example the Standard Devi-
   ation remains the same. What introduces a distortion is the effect
   of the drift, even if 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.

<a>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 fixed action of the 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.

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.

9. References

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