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**Packet Delay Variation Applicability Statement**  
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Abstract

Packet delay variation metrics appear in many different standards documents. The metric definition in [RFC 3393](#) has considerable flexibility, and it allows multiple formulations of delay variation through the specification of different packet selection functions.

Although flexibility provides wide coverage and room for new ideas, it can be a challenge when attempting to make comparisons. Two different formulations of delay variation have come into wide use in

the context of active measurements. This memo examines a range of circumstances for active measurements of delay variation and their uses, and recommends which of the two forms is best matched to particular conditions and tasks.

#### Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [[RFC2119](#)].

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## **1 Introduction**

There are many ways to formulate packet delay variation metrics for the Internet and other IP-based networks. The IETF itself has several specifications for delay variation [[RFC3393](#)], sometimes called jitter [[RFC3550](#)], and these have achieved wide adoption. The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) has also recommended several delay variation metrics (called parameters in their terminology) [[Y.1540](#)] [[G.1020](#)], and some of these are widely cited and used. Most of the standards above specify more than one way to quantify delay variation, so one can conclude that standards efforts have tended to be inclusive rather than selective.

This memo uses the term "delay variation" for metrics that quantify a path's ability to transfer packets with consistent delay. [[RFC3393](#)] and [[Y.1540](#)] both prefer this term. Some refer to this phenomenon as "jitter" (and the buffers that attempt to smooth the variations as de-jitter buffers). Applications of the term "jitter" are much broader than packet transfer performance, with "unwanted signal variation" as a general definition. "Jitter" has been used to describe frequency or phase variations, such as data stream rate variations or carrier signal phase noise. The phrase "packet delay variation" is almost self-defining and more precise, so it is preferred in this memo.

Most (if not all) delay variation metrics are derived metrics, in that their definitions rely on another fundamental metric. In this case, the fundamental metric is one-way delay, and variation is assessed by computing the difference between two individual one-way delay measurements, or a pair of singletons. One of the delay singletons is taken as a reference, and the result is the variation with respect to the reference. The variation is usually summarized for all packets in a stream using statistics.

Two main formulations of delay variation are preferred (according to [[Krzanowski](#)]):

1. Inter-Packet Delay Variation, IPDV, where the reference is the previous packet in the stream (according to sending sequence), and the reference changes for each packet in the stream. Properties of variation and packet sequence are captured in this formulation.
2. Packet Delay Variation, PDV, where a single reference is chosen from the stream based on specific criteria, and the reference is fixed once selected. The most common criterion for the reference is the packet with the minimum delay in the sample.

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It is important to note that the authors of relevant standards for delay variation recognized there are many different users with varying needs, and allowed sufficient flexibility to formulate several metrics with different properties. Therefore, the comparison is not so much between standards bodies or their specifications as it is between specific formulations of delay variation. For instance, both Inter-Packet Delay Variation and Packet Delay Variation can be assessed using options of [[RFC3393](#)], especially the packet selection function.

The IPPM framework [[RFC2330](#)] and other RFCs describing IPPM metrics provide a background for this memo, especially for terms such as singleton, sample, and statistic.

## **2 Purpose and Scope**

The IPDV and PDV formulations have certain features that make them more suitable for one circumstance and less so for another. The purpose of this memo is to compare two forms of delay variation, so that it will be evident which of the two is better suited for each of many possible uses and their related circumstances.

The scope of this memo is limited to the two forms of delay variation briefly described above (Inter-Packet Delay Variation and Packet Delay Variation), circumstances related to active measurement, and uses that are deemed relevant and worthy of inclusion here through IPPM Working Group consensus.

The scope excludes assessment of delay variation for packets with undefined delay. This is accomplished by conditioning the delay distribution on arrival within a reasonable waiting time based on an understanding of the path under test and packet lifetimes. The waiting time is sometimes called the loss threshold [[RFC2680](#)]: if a packet arrives beyond this threshold, it may as well have been lost because it is no longer useful. This is consistent with [[RFC3393](#)], where the Type-P-One-way-ipdv is undefined when the destination fails to receive one or both packets in the selected pair. Furthermore, it is consistent with application performance analysis to consider only arriving packets, because a finite waiting time-out is a feature of many protocols.

## **3 Uses and Circumstances for Delay Variation Metrics**

This section presents a set of tasks that call for delay variation measurements and their possible circumstances.





### **3.1 Uses**

Here, the memo provides several answers to the question, "How will the results be used?" for the delay variation metric.

#### **3.1.1 Determining De-jitter Buffer Size**

Most Isochronous applications (a.k.a. real-time applications) employ a buffer to smooth out delay variation encountered on the path from source to destination. The buffer must be big enough to accommodate (most of) the expected variation, or packet loss will result. However, if the buffer is too large, then some of the desired spontaneity of communication will be lost and conversational dynamics will be affected. Therefore, application designers need to know the extent of delay variation they must accommodate, whether they are designing fixed or adaptive buffer systems.

Network service providers also attempt to constrain delay variation to ensure the quality of real-time applications, and monitor this metric (possibly to compare with a numerical objective or Service Level Agreement).

#### **3.1.2 Inferring Queue Occupation on a Path**

As packets travel along the path from source to destination, they pass through many network elements, including a series of router queues. Some types of the delay sources along the path are constant, such as links between two locations. But the latency encountered in each queue varies, depending on the number of packets in the queue when a particular packet arrives. If one assumes that at least one of the packets in a test stream encounters virtually empty queues all along the path (and the path is stable), then the additional delay observed on other packets can be attributed to the time spent in one or more queues. Otherwise, the delay variation observed is the variation in queue time experienced by the test stream.

#### **3.1.3 Spatial Composition**

In Spatial Composition, the tasks are similar to those described above, but with the additional complexity of a multiple network path where several sub-paths are measured separately, and no source to destination measurements are available. In this case, the source to destination performance must be estimated, using Composed Metrics as described in [[I-D.ietf-ippm-framework-compagg](#)] and [[Y.1541](#)]. Note that determining the composite delay variation is not trivial: simply summing the sub-path variations is not accurate.

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### **3.1.4 Service Level Comparison**

IP performance measurements are often used as the basis for agreements (or contracts) between service providers and their customers. The measurement results must compare favorably with the performance levels specified in the agreement.

Packet delay variation is usually one of the metrics specified in these agreements. In principle, any formulation could be specified in the Service Level Agreement (SLA). However, the SLA is most useful when the measured quantities can be related to ways in which the communication service will be utilized by the customer, and this can usually be derived from one of the tasks described above.

### **3.1.5 <your favorite here>**

## **3.2 Challenging Circumstances**

Any of the tasks above are made more "interesting" when certain circumstances are present. Among these are:

1. Low cost or low complexity measurement systems. These systems may be embedded in communication devices that do not have access to high stability clocks, and time errors will almost certainly be present. However, larger time-related errors may offer an acceptable trade-off for monitoring performance over a large population (the accuracy needed to detect problems may be much than required for a scientific study). These devices may not have sufficient memory to store all singletons for later processing.
2. Extremely dynamic network conditions. When there is little or no stability in the network under test, then the devices that attempt to characterize the network are equally stressed, especially if the results displayed are used to make inferences which may not be valid. Frequent path changes and prolonged congestion with substantial packet loss clearly make delay variation measurements challenging.

## **4 Formulations of IPDV and PDV**

This section presents the formulations of IPDV and PDV, and provides some illustrative examples. We use the basic singleton definition in [[RFC3393](#)] (which itself is based on [[RFC2679](#)]):

"Type-P-One-way-ipdv is defined for two packets from Src to Dst selected by the selection function F, as the difference between the



value of the Type-P-One-way-delay from Src to Dst at T2 and the value of the Type-P-One-Way-Delay from Src to Dst at T1."

#### **4.1 IPDV: Inter-Packet Delay Variation**

An example selection function given in [RFC3393] is "Consecutive Type-P packets within the specified interval." This is exactly the function needed for IPDV. The reference packet in the pair is always the previous packet in the sending sequence.

If we have packets in a stream consecutively numbered  $i = 1, 2, 3, \dots$  falling within the test interval, then  $IPDV(i) = D(i) - D(i-1)$  where  $D(i)$  denotes the one-way-delay of the  $i$ th packet of a stream.

Note that IPDV can take on positive and negative values (and zero), although one of the useful ways to analyze the results is to concentrate on the positive excursions. This is discussed in more detail below.

#### **4.2 PDV: Packet Delay Variation**

(The name Packet Delay Variation is from [Y.1540], and refers to a performance parameter equivalent to the metric described below.)

The Selection Function for PDV requires two specific roles for the packets in the pair. The first packet is any Type-P packet within the specified interval. The second, or reference packet is the Type-P packet within the specified interval with the minimum one-way-delay.

Therefore,  $PDV(i) = D(i) - D(\min)$  (using the nomenclature introduced in the IPDV section).  $D(\min)$  is the delay of the packet with the lowest value for delay (minimum) over the current test interval. Values of PDV may be zero or positive, and quantiles of the PDV distribution are direct indications of delay variation.

#### **4.3 Examples and Initial Comparisons**

This section will discuss the examples in slides 2 and 3 of

<http://www3.ietf.org/proceedings/06mar/slides/ippm-4.pdf>

### **5 Earlier Comparisons**

This section summarizes previous work to compare these two forms of delay variation.



## 5.1 Demichelis' Comparison

In [[Demichelis](#)], Demichelis compared the early draft versions of the two forms we consider here. Although the IPDV form would eventually be standardized under the IETF IPPM effort, the ITU-T work cited here was significantly modified based on further study and analysis. Demichelis considered the possibilities of using the delay of the first packet in the stream and the mean delay of the stream as the PDV reference packet. Neither of these alternative references were used in practice, and they are now depreciated in favor of the minimum delay of the stream [[Y.1540](#)] .

Active measurements of a transcontinental path (Torino to Tokyo) provided the data for the comparison. The Poisson test stream had 0.764 second average inter-packet interval, with more than 58 thousand packets over 13.5 hours. Among Demichelis' observations about IPDV are the following:

1. IPDV is a measure of the network's ability to preserve the spacing between packets.
2. The distribution of IPDV is usually symmetrical about the origin, having a balance of negative and positive values (for the most part). The mean is usually zero, unless some long-term delay trend is present.
3. IPDV distinguishes quick delay variations (on the order of the interval between packets) from longer term variations.
4. IPDV places reduced demands on the stability and skew of measurement clocks.

He also notes these features of PDV:

1. PDV does not distinguish quick variation from variation over the complete test interval.
2. The location of the distribution is very sensitive to the delay of the first packet, if this packet is used as the reference.
3. The shape of the PDV distribution is identical to the delay distribution, but shifted by the reference delay.
4. Use of a common reference over long measurement intervals can indicate more PDV than would be experienced by streams that support shorter interval sessions.





5. PDV characterizes the range of queue occupancies along the measurement path (assuming the path is fixed), but the range says nothing about how the variation took place.

The summary metrics used in this comparison were the number of values exceeding a +/-50ms range around the mean, the Inverse Percentiles, and the Inter-Quartile Range.

## **5.2 Ciavattone et al.**

In [[Cia03](#)], the authors compared IPDV and PDV (referred to as delta) using a periodic packet stream conforming to [[RFC3432](#)] with inter-packet interval of 20 ms.

One of the comparisons between IPDV and PDV involves a laboratory set-up where a queue was temporarily congested by a competing packet burst. The additional queuing delay was 85ms to 95ms, much larger than the inter-packet interval. The first packet in the stream that follows the competing burst spends the longest time enqueued, and others experience less and less queuing time until the queue is drained.

The authors observed that PDV reflects the additional queuing time of the packets affected by the burst, with values of 85, 65, 45, 25, and 5ms. Also, it is easy to determine (by looking at the PDV range) that a de-jitter buffer of 90 ms would have been sufficient to accommodate the delay variation.

The distribution of IPDV values in the congested queue example are very different: 85, -20, -20, -20, -20, -5ms. Only the positive excursion of IPDV gives an indication of the de-jitter buffer size needed. Although the variation exceeds the inter-packet interval, the extent of negative IPDV values is limited by that sending interval. This preference for information from the positive IPDV values has prompted some to ignore the negative values, or to take the absolute value of each IPDV measurement (sacrificing key properties of IPDV in the process, such as its ability to distinguish delay trends).

Elsewhere, the authors considered the range as a summary statistic for IPDV, and the 99.9%-ile minus the minimum delay as a summary statistic for delay variation, or PDV.

## **5.3 IPPM List Discussion from 2001**

Summary To Be Provided. But to indicate one of the key points:

IPDV values can be viewed as the adjustments that an adaptive de-



jitter buffer would make, IF it could make adjustments on a packet-by-packet basis. However, adaptive de-jitter buffers don't make adjustments so frequently, so in this respect IPDV provides "too much information".

#### [5.4](#) **Y.1540** [Appendix II](#)

This Appendix compares IPDV, PDV (referred to as 2-point PDV), and 1-point packet delay variation (which assume a periodic stream and assesses variation against an ideal arrival schedule constructed at the single measurement point).

### [6](#) **Additional Properties and Comparisons**

This section treats some of the earlier comparison areas in more detail, and introduces new areas for comparison.

#### [6.1](#) **Jitter in RTCP Reports**

[RFC3550] gives the calculation of the inter-arrival Jitter field for the RTCP report, with a sample implementation in an Appendix.

The RTCP Jitter value can be calculated using IPDV singletons. If there is packet reordering, as defined in [[I-D.ietf-ippm-reordering](#)], then estimates of Jitter based on IPDV may vary slightly, because [[RFC3550](#)] specifies the use of receive packet order.

Just as there is no simple way to convert PDV singletons to IPDV singletons without returning to the original sample of delay singletons, there is no clear relationship between PDV and [[RFC3550](#)] Jitter.

#### [6.2](#) **Path Changes**

Sometimes the path characteristics change during a measurement interval. The change may be due to link or router failure, administrative changes prior to maintenance (e.g., link cost change), or re-optimization of routing using new information. All these causes are usually infrequent, and network providers take appropriate measures to ensure this. Automatic restoration to a back-up path is seen as a desirable feature of IP networks.

Path changes are usually accompanied by a persistent increase or decrease in one-way-delay. [[Cia03](#)] gives one such example. We assume that a restoration path either accepts a stream of packets, or is not used for that particular stream (e.g., no multi-path for flows).



In any case, a change in the TTL (or Hop Limit) of the received packets indicates that the path is no longer the same. Transient packet reordering may also be observed with path changes, due to use of non-optimal routing while updates propagate through the network (see [[Casner](#)] and [[Cia03](#)] )

Many, if not all, packet streams experience packet loss in conjunction with a path change. However, it is certainly possible that the active measurement stream does not experience loss. This may be due to use of a long inter-packet sending interval with respect to the restoration time, and this becomes more likely as "fast restoration" techniques see wider deployment.

Thus, there are two main cases to consider, path changes accompanied by loss, and those that are lossless from the point of view of the active measurement stream.

#### **6.2.1 Lossless Path Change**

In the lossless case, a path change will typically affect only two IPDV singletons. However, if the change in delay is negative and larger than the inter-packet sending interval, then more than two IPDV singletons may be affected because packet reordering is also likely to occur.

The use of the new path and its delay variation can be quantified by treating the PDV distribution as bi-modal, and characterizing each mode separately. This would involve declaring a new path within the sample, and using a new local minimum delay as the PDV reference delay for the sub-sample (or time interval) where the new path is present.

The process of detecting a bi-modal delay distribution is made difficult if the typical delay variation is larger than the delay change associated with the new path. However, information on TTL (or Hop Limit) change or the presence of transient reordering can assist in an automated decision.

The effect of path changes may also be reduced by making PDV measurements over short intervals (minutes, as opposed to hours). This way, a path change will affect one sample and its PDV values. Assuming that the mean or median one-way-delay changes appreciably on the new path, then subsequent measurements can confirm a path change, and trigger special processing on the interval containing a path change and the affected PDV result.



### **6.2.2 Path Change with Loss**

If the path change is accompanied by loss, such that there are no consecutive packet pairs that span the change, then no IPDV singletons will reflect the change. This may or may not be desirable, depending on the ultimate use of the delay variation measurement.

PDV will again produce a bimodal distribution. But here, the decision process to define sub-intervals associated with each path is further assisted by the presence of loss, in addition to TTL, reordering information, and use of short measurement intervals consistent with the duration of user sessions. It is reasonable to assume that at least loss and delay will be measured simultaneously with PDV or IPDV.

### **6.3 Measurement Clock Issues**

As mentioned above, [[Demichelis](#)] observed that PDV places greater demands on clock synchronization than for IPDV. This observation deserves more discussion. Synchronization errors have two components: time of day errors and clock frequency errors (resulting in skew).

Both IPDV and PDV are sensitive to time-of-day errors when attempting to align measurement intervals at the source and destination. Gross mis-alignment of the measurement intervals can lead to lost packets, for example if the receiver is not ready when the first test packet arrives. However, both IPDV and PDV assess time differences, so the error present in two one-way-delay singletons will cancel as long as it is constant.

Skew is a measure of the change in clock time over an interval w.r.t. a reference clock. Both IPDV and PDV are affected by skew, but the error sensitivity in IPDV singletons is less because the intervals between consecutive packets are rather small, especially when compared to the overall measurement interval. Since PDV computes the difference between a single reference delay (the sample minimum) and all other delays in the measurement interval, the constraint on skew error is greater to attain the same accuracy as IPDV. Again, use of short PDV measurement intervals (on the order of minutes, not hours) provides some relief from the effects of skew error.

If skew is present in a sample of one-way-delays, its symptom is typically a linear growth or decline over all the one-way-delay values. As a practical matter, if the same slope appears consistently in the measurements, then it may be possible to fit the slope and compensate for the skew in the one-way-delay measurements,





thereby avoiding the issue in the PDV calculations that follow. See [\[RFC3393\]](#) for additional information on compensating for skew.

#### **6.4 Reporting a Single Number**

Despite the risk of over-summarization, measurements must often be displayed for easy consumption. If the right summary report is prepared, then the "dashboard" view correctly indicates whether there is something different and worth investigating further, or that the status has not changed. The dashboard model restricts every instrument display to a single number. The packet network dashboard could have different instruments for loss, delay, delay variation, reordering, etc., and each must be summarized as a single number for each measurement interval.

The simplicity of the PDV distribution lends itself to this summarization process (including use of the median or mean). [\[Y.1541\]](#) introduced the notion of a pseudo-range when setting an objective for the 99.9%-ile of PDV. The conventional range (max-min) was avoided for several reasons, including stability of the maximum delay. The 99.9%-ile of PDV is helpful to performance planners (seeking to meet some user-to-user objective for delay) and in design of de-jitter buffer sizes, even those with adaptive capabilities.

IPDV does not lend itself to summarization so easily. The mean IPDV is typically zero. As the IPDV distribution may have two tails (positive and negative) the range or pseudo-range would not match the needed de-jitter buffer size. Additional complexity may be introduced when the variation exceeds the inter-packet sending interval, as discussed above. Should the Inter-Quartile Range be used? Should the singletons beyond some threshold be counted (e.g., mean +/- 50ms)? A strong rationale for one of these summary statistics has yet to emerge.

#### **6.5 MAPDV2**

MAPDV2 stands for Mean Absolute Packet Delay Variation (version) 2, and is specified in [\[G.1020\]](#). The MAPDV2 algorithm computes a smoothed running estimate of the mean delay using the one-way delays of 16 previous packets. It compares the current one-way-delay to the estimated mean, separately computes the means of positive and negative deviations, and sums these deviation means to produce MAPVDV2. In effect, there is a MAPDV2 singleton for every arriving packet, so further summarization is usually warranted.

Neither IPDV or PDV assists in the computation of MAPDV2.



## **7 Applicability of the Delay Variation Forms**

Based on the comparisons of IPDV and PDV presented above, this section matches the attributes of each form with the tasks described in [section 3](#). We discuss the more general circumstances first.

Note: the conclusions of this section should be regarded as preliminary, pending discussion and further development by the IPPM WG.

### **7.1 Challenging Circumstances**

When appreciable skew is present between measurement system clocks, then IPDV has a clear advantage, since that PDV would require processing over the entire sample to remove the skew error. Neither form of delay variation is more suited than the other to on-the-fly summarization without memory, and this is one of the reasons that [\[RFC3550\]](#) RTCP Jitter and MAPDV2 in [\[G.1020\]](#) have attained deployment in low-cost systems.

If the network under test exhibits frequent path changes, on the order of several new routes per minute, then IPDV appears to isolate the delay variation on each path from the transient effect of path change (especially if there is packet loss at the time of path change). It is possible to make meaningful PDV measurements when paths are unstable, but great importance would be placed on the algorithms that infer path change and attempt to divide the sample on path change boundaries.

If the network under test exhibits frequent loss, then PDV may produce a larger set of singletons for the sample than IPDV. This is due to IPDV requiring consecutive packet arrivals to assess delay variation, compared to PDV where any packet arrival is useful. The worst case is when no consecutive packets arrive, and the entire IPDV sample would be undefined. PDV would successfully produce a sample based on the arriving packets.

Note that delay variation may not be the top concern under these unstable and unreliable circumstances, as this author has pointed-out many times in discussion.

### **7.2 Spatial Composition**

ITU-T Recommendation [\[Y.1541\]](#) gives a provisional method to compose a PDV metric using PDV measurement results from two or more sub-paths.

PDV has a clear advantage at this time, since there is no known method to compose an IPDV metric. In addition, IPDV results depend



greatly on the exact sequence of packets and may not lend themselves easily to the composition problem.

### **7.3 Inferring Queue Occupancy**

The PDV distribution is anchored at the minimum delay observed in the measurement interval. When the sample minimum coincides with the true minimum delay of the path, then the PDV distribution is equivalent to the queuing time distribution experienced by the test stream. If the minimum delay is not the true minimum, then the PDV distribution captures the variation in queuing time and some additional amount of queuing time is experienced, but unknown. One can summarize the PDV distribution with the mean, median, and other statistics.

IPDV can capture the difference in queuing time from one packet to the next, but this is a different distribution from the queue occupancy revealed by PDV.

### **7.4 Determining De-jitter Buffer Size**

This task is complimentary to the problem of inferring queue occupancy through measurement. Again, use of the sample minimum as the reference delay for PDV yields a distribution that is very relevant to de-jitter buffer size. This is because the minimum delay is an alignment point for the smoothing operation of de-jitter buffers. A de-jitter buffer that is ideally aligned with the delay variation adds zero buffer time to packets with the longest accommodated network delay (any packets with longer delays are discarded). Thus, a packet experiencing minimum network delay should be aligned to wait the maximum length of the de-jitter buffer. With this alignment, the stream is smoothed with no unnecessary delay added. [\[G.1020\]](#) illustrates the ideal relationship between network delay variation and buffer time.

The PDV distribution is also useful for this task, but different statistics are preferred. The range (max-min) or the 99.9%-ile of PDV (pseudo-range) are closely related to the buffer size needed to accommodate the observed network delay variation.

In some cases, the positive excursions of IPDV may help to approximate the de-jitter buffer size, but there is no guarantee that a good buffer estimate will emerge, especially when the delay varies as a positive trend over several test packets.



## **8 IANA Considerations**

This document makes no request of IANA.

Note to RFC Editor: this section may be removed on publication as an RFC.

## **9 Security Considerations**

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

## **10 Acknowledgements**

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