International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.8260

(08/2010)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Packet over Transport aspects – Quality and availability targets

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Definitions and terminology for synchronization in packet networks

Recommendation ITU-T G.8260

ITU-T

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Recommendation ITU-T G.8260

Definitions and terminology for synchronization in packet networks

Summary

Recommendation ITU-T G.8260 provides the definitions, terminology and abbreviations used in ITU-T Recommendations on timing and synchronization in packet networks.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.8260	2010-08-12	15

Keywords

Frequency phase and time, packet delay variation, synchronization definitions.

FOREWORD

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Definitions and terminology for synchronization in packet networks

1 Scope

This Recommendation provides the definitions, terminology and abbreviations used in Recommendations on frequency, phase and time synchronization in packet networks. It includes mathematical definitions for various synchronization stability and quality metrics for packet networks, and also provides background information on the nature of packet timing systems and the impairments created by packet networks.

Ethernet physical layer methods for synchronization are based on traditional time division multiplexing (TDM) physical layer synchronization and therefore most of the definitions related to these methods are covered by [ITU-T G.810]. Additional definitions are included in this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.810] Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.

[ITU-T G.8261] Recommendation ITU-T G.8261/Y.1361 (2008), *Timing and synchronization aspects in packet networks*.

[ITU-T Y.1413] Recommendation ITU-T Y.1413 (2004), *TDM-MPLS network interworking – User plane interworking*.

[IEEE 1588] IEEE Standard 1588-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*.

3 Abbreviations and acronyms

For the purposes of Recommendations on timing and synchronization in packet networks, the following abbreviations apply:

ADEV Allan DEViation

CES Circuit Emulation Services

GPS Global Positioning System

IWF Inter-Working Function

MDEV Modified Allan DEViation

MTIE Maximum Time Interval Error

NTP Network Time Protocol

PDV Packet Delay Variation

PTP Precision Time Protocol

TAI International Atomic Time

TDEV Time DEViation

TDM Time Division Multiplexing

UTC Coordinated Universal Time

4 Definitions

For the purposes of Recommendations on timing and synchronization in packet networks, the following definitions apply:

4.1 Terms defined in this Recommendation

This Recommendation defines the following terms:

4.1.1 adaptive clock recovery: Clock recovery technique that does not require the support of a network-wide synchronization signal to regenerate the timing. In this case, the timing recovery process is based on the (inter-)arrival time of the packets (e.g., timestamps or circuit emulation service (CES) packets). The information carried by the packets could be used to support this operation. Two-way or one-way protocols can be used.

4.1.2 floor delay: The notion of "floor delay" is equivalent to the notion of minimum possible transit delay of packets over a network. It may be useful to distinguish the notions of "*absolute floor delay*" and "*observed floor delay*":

- **absolute floor delay**: Absolute minimum possible transit delay of packets of a given size over a network. This may generally be described as the transit delay experienced by a packet that has experienced the minimum possible delay through each network element along a specified path. Depending on loading and other considerations, it is possible that in any given finite window of observation interval a packet with delay equal to this absolute minimum may not be observed. Full knowledge of the packet network, network elements, and routing path must be known in order to perform a theoretical analysis of the minimum transit delay.
- **observed floor delay**: Minimum transit delay of packets of a given size over a network observed over a given observation interval (for instance, during a packet delay variation (PDV) measurement).

NOTE – As mentioned above, the observed floor delay during a PDV measurement may differ from the absolute floor delay.

4.1.3 packet-based method: Timing distribution method (for frequency and/or time and/or phase) where the timing information is associated with packets.

- The frequency can be recovered using two-way or one-way protocols.
- Time and phase information is recovered with a two-way protocol in order to compensate for the transfer delay from packet master clock to packet slave clock.

4.1.4 packet-based method without timing support from the network: Packet-based method (frequency or time-phase synchronization) where the timing packets are transported over a timing transport agnostic network.

4.1.5 packet-based method with timing support from the network: Packet-based method (frequency or time-phase synchronization) requiring that all the network nodes on the path of the synchronization flow implement one of the two following types of functional support:

- termination and regeneration of the timing (e.g., NTP stratum clocks, PTP boundary clock);

- a mechanism to measure the delay introduced by the network node and/or the connected links (e.g., PTP transparent clock) so that the delay variation can be compensated using this information.

4.1.6 packet master clock: A clock that measures the precise times at which the significant instants of a packet timing signal pass the master's timing reference point (e.g., as they enter the network from the packet master clock, or as they enter the packet master clock from the network). These measurements are done relative to the master clock's local time-scale. They are forwarded to, and used to control, one or more packet slave clocks.

NOTE – In the case of a periodic packet timing signal (used for one-way frequency distribution), the event packets enter the network from the packet master clock at regular intervals, such that the master's timing information is implied from the nominal frequency of the packets.

4.1.7 packet slave clock: A clock whose timing output is frequency locked, or phase aligned, or time aligned to one or more reference packet timing signals exchanged with a higher quality clock.

4.1.8 packet timing signal: A signal, consisting of a series of event packets or frames, that is used to convey timing information from a packet master clock to a packet slave clock.

Event packets in a packet timing signal may travel from a packet master clock to a packet slave clock or vice versa, but the flow of timing information is always in the direction from master to slave.

The significant instants of the packet timing signal are measured relative to the master's local time-scale as they pass the master's timing reference point, and these measurements are communicated to the packet slave clock.

The significant instants of the packet timing signal are also measured relative to the slave's local time-scale as they pass the slave's timing reference point

NOTE 1 – The significant instants of the signal are the set of times that a defined location in each event packet or frame passes a given reference point in the network (e.g., the interface between the packet master clock and the network). Conventionally the defined location is the end of the start-of-frame delimiter, but it may be defined differently in any given packet timing protocol provided the definition is consistent.

NOTE 2 – In the case of a periodic packet timing signal, the master's timing information is implied from the nominal frequency of the packets.

4.1.9 phase synchronization: The term phase synchronization implies that all associated nodes have access to reference timing signals whose significant events occur at the same instant (within the relevant phase accuracy requirement). In other words, the term phase synchronization refers to the process of aligning clocks with respect to phase (phase alignment). This is shown in Figure 1.

NOTE 1 – Phase synchronization includes compensation for delay between the (common) source and the associated nodes.

NOTE 2 – This term might also include the notion of frame timing (that is, the point in time when the timeslot of an outgoing frame is to be generated).

NOTE 3 – The concept of phase synchronization (phase alignment) should not be confused with the concept of phase-locking where a fixed phase offset is allowed to be arbitrary and unknown. Phase alignment implies that this phase offset is nominally zero. Two signals which are phase-locked are implicitly frequency synchronized. Phase-alignment and phase-lock both imply that the time error between any pair of associated nodes is bounded.

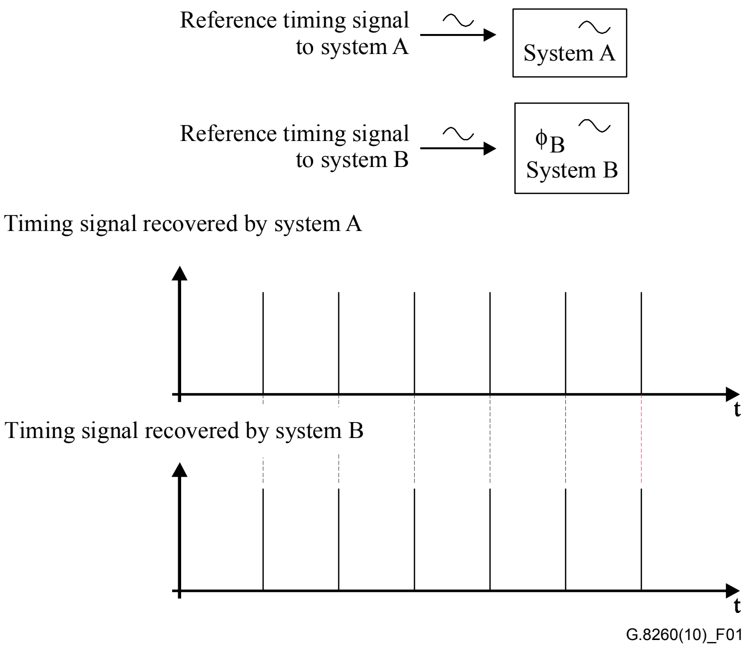

Figure 1 – Phase synchronization

4.1.10 packet network timing function (PNT-F): The set of functions within the inter-working functional (IWF) that supports the synchronization network clock domain (see Figure B.2 of [ITU-T G.8261]). This includes the function to recover and distribute the timing carried by the synchronization network. The PNT-F clocks may be part of the IWF or may be part of any other network element in the packet network.

When the PNT-Fs are part of the IWF, they may support the CES IWF and/or change the layer over which timing is carried (i.e., from packet to physical layer and vice versa).

4.1.11 primary reference time clock (PRTC): A reference time generator that provides a reference timing signal traceable to a recognized time standard (e.g., UTC).

4.1.12 time clock: An equipment that provides the elapsed time from a reference epoch.

4.1.13 time synchronization: Time synchronization is the distribution of a time reference to the real-time clocks of a telecommunication network. All the associated nodes have access to information about time (in other words, each period of the reference timing signal is marked and dated) and share a common time-scale and related epoch (within the relevant time accuracy requirement), as shown in Figure 2.

Examples of time-scales are:

- UTC;
- TAI;
- UTC + offset (e.g., local time);
- GPS;
- PTP;
- local arbitrary time.

Note that distributing time synchronization is one way of achieving phase synchronization.

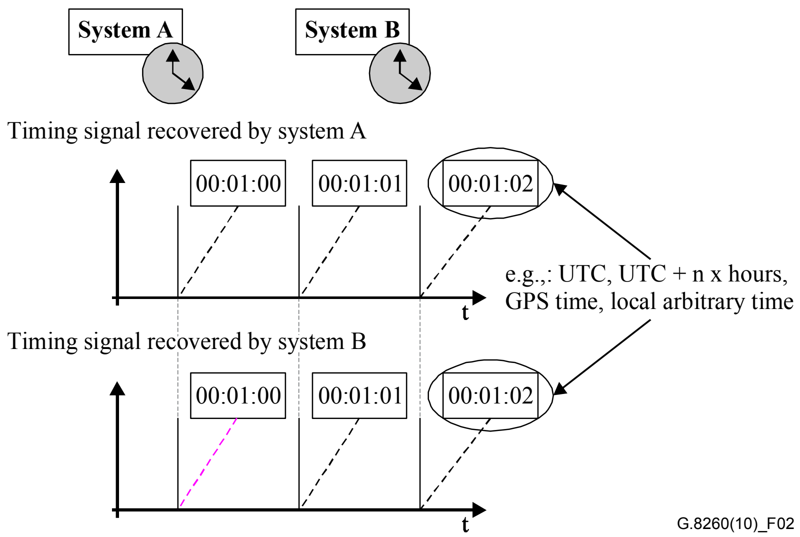

Figure 2 – Time synchronization

5 Conventions

No conventions are used in this Recommendation.

6 Description of packet timing concepts

6.1 The nature of packet timing

A simplistic view of a generic slave clock is that it takes frequency information in, and puts frequency information out, as shown in Figure 3:

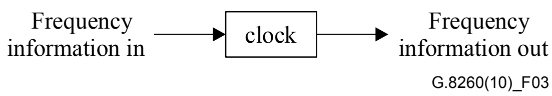

Figure 3 – Generic slave clock

Conventionally, this frequency information is encoded as a timing signal. This is typically implemented as a periodic digital signal, where the edges of the signal are reference points in time known as the "significant instants" of the signal. Timing jitter and wander causes these significant instants to vary slightly from their ideal position in time, i.e., they may not occur at precisely equally spaced points in time. A physical-layer timing signal is shown in Figure 4.

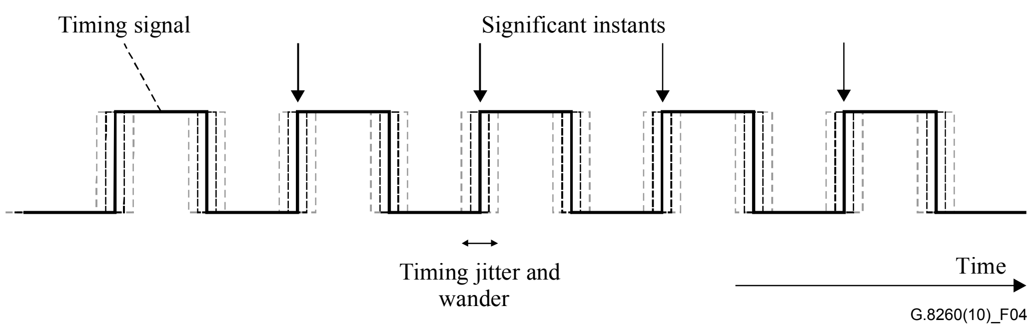

Figure 4 – Physical-layer timing signal

A packet timing signal is similar in concept. The frequency is encoded as a series of time-critical packets in a network, known as "event packets". While the transmission medium is different (packets on a network as opposed to signals on a wire), the packets still contain significant instants (normally the front edge of the packet), with a defined ideal position in time. The variation of the significant instants around their ideal position is termed "packet delay variation" (PDV). This is shown in Figure 5:

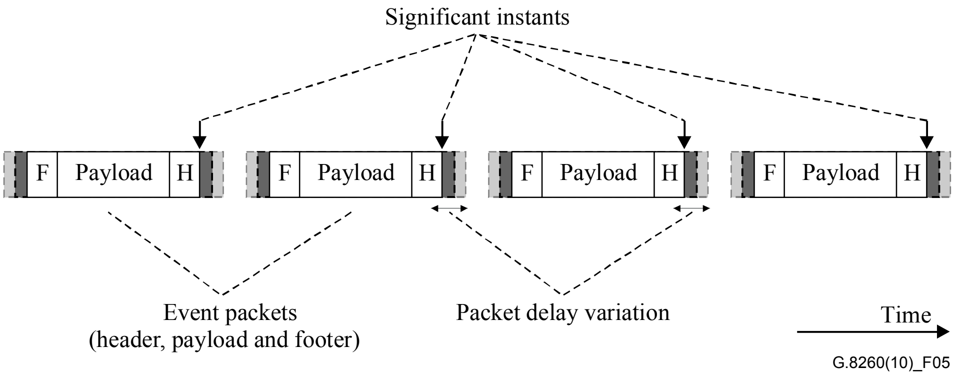

Figure 5 – Packet timing signal

Some of the causes and characteristics of packet delay variation and other impairments that may be introduced by the packet network are discussed in clause 10 of [ITU-T G.8261].

Some packet timing signals may be periodic (e.g., circuit emulation packets containing constant bit rate data), and for these the ideal position in time is implicitly given by the packet rate. Other packet timing signals are not periodic (e.g., PTP or NTP), and for these the ideal position in time is given by a timestamp embedded in the packet data. It is important to note that both periodic and non-periodic packet timing signals are still time domain signals. It is the position in time of the packets that is significant, not the contents of the packets.

6.2 Differences between packet-based and physical-layer timing systems

Packet-based timing systems are not fundamentally different from physical-layer timing systems. Conceptually, both utilize timing signals which are sequences of periodic or timed events, termed "significant instants", where there is a notion of the "ideal position in time" for each event. Similarly, after transmission of these timing signals through the network, there will be some phase noise component, corrupting this "ideal position in time". The recovery of the original timing signal is achieved by filtering the incoming timing signal to remove the transport-related phase noise and generate a clean output.

However, there are some differences which lead to packet timing signals having different characteristics to physical-layer timing signals:

- Rate of significant instants:

  The packet rate in a packet timing signal is much lower than the frequency of most physical-layer timing signals. For example, in PTP (defined in [IEEE 1588]), the *sync* message rate will normally be in the range 1-128 Hz, while a conventional E1 timing signal has a frequency of 2.048 MHz.

  Secondly, the packets that form the significant instants need not be sent at precisely regular intervals. While the mean rate is specified, the intervals between packets may vary. Timestamps are used to identify the precise sending time, relative to a pre-determined epoch.

- Amplitude and nature of noise processes:

  The principal cause of noise in a packet timing system is packet delay variation (PDV). The amplitude and distribution of PDV is much larger than jitter and wander in physical layer timing systems, and it may contain very low frequency components such as diurnal wander due to network loading variations.

  Unlike physical layer noise, the PDV depends not only on the physics of components but also on the architecture and implementation of network elements. Therefore, the noise is more complex and harder to model.

6.3 Classes of packet clocks

There can be several classes of packet-based clocks, depending on the combination of input and output timing signal classes. Table 1 shows the different classes, with real-world examples of each case.

Table 1 – Classes of packet-based clocks

Packet-based clock class	Input timing signal	Output timing signal	Examples
Packet master clock	Physical-layer timing signal	Packet timing signal	PTP master, NTP server Ingress CES IWF (Note 1)
Packet slave clock	Packet timing signal	Physical-layer timing signal	PTP slave, NTP client Egress CES IWF (Note 2)
Combined packet slave clock and packet master clock	Packet timing signal	Packet timing signal	PTP boundary clock NTP stratum *n* server ($n > 1$)
NOTE 1 – i.e., TDM to packet direction, see term "ingress IWF" in [ITU-T Y.1413]. NOTE 2 – i.e., packet to TDM direction, see term "egress IWF" in [ITU-T Y.1413].			

6.4 Two-way timing protocols

Packet timing signals may flow from packet master clock to packet slave clock or vice versa. However, in each case, the flow of timing and synchronization is always from master to slave.

In the case of a packet timing signal flowing from a packet master clock to a packet slave clock (e.g., the PTP *sync* messages), the time of exit of each event packet from the packet master clock is measured (to be precise, the time relative to the master's time-scale at which the significant instant of each event packet passes the master's timing reference point). This information is sent to the packet slave clock either in a timestamp embedded in the event packet, or in a subsequent information packet (e.g., the PTP *follow_up* message).

On reception at the packet slave clock, the arrival time of the event packet is measured (to be precise, the time relative to the slave's local time-scale at which the significant instant of each event packet passes the slave's timing reference point). The two times are compared, creating a series of time differences. These time differences are then filtered, and may be used to control the frequency of the output timing signal.

In the case of a packet timing signal flowing from a packet slave clock to a packet master clock (e.g., the PTP *delay_request* messages), the time of exit of each event packet from the packet slave clock is measured. On reception at the packet master clock, the arrival time of each event packet is measured, and this information is sent to the packet slave clock in a subsequent information packet (e.g., the PTP *delay_response* message).

The use of a two-way timing protocol (such as PTP or NTP) makes it possible to align the local time-scale to the master time-scale. The four times may be used to calculate the round-trip delay of the message exchange, and hence to calculate the time offset between the local and master time-scales.

The timing message exchange is shown in Figure 6:

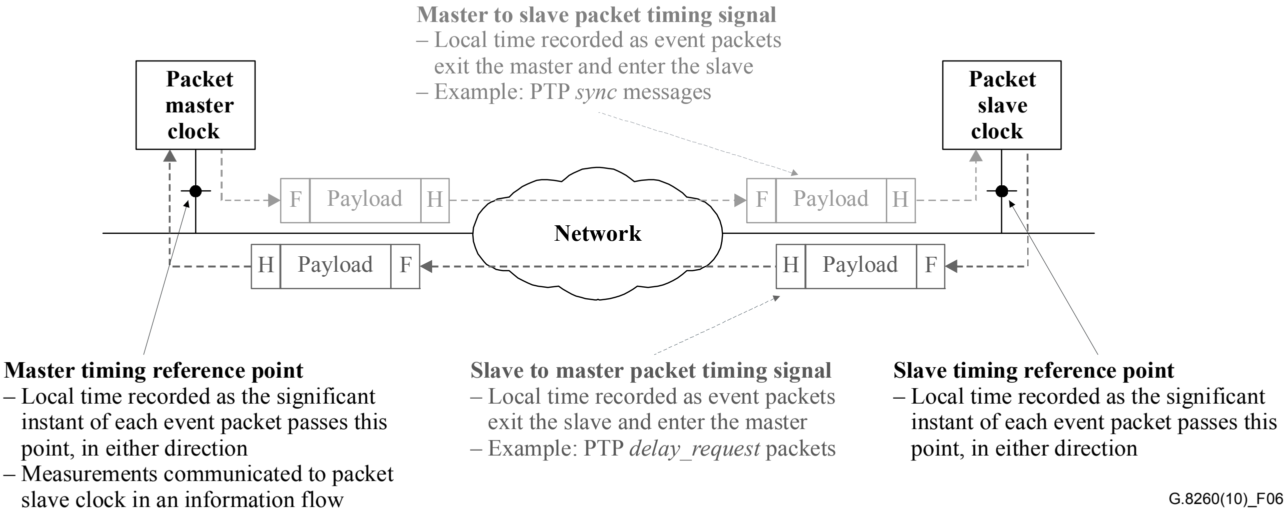

Figure 6 – Packet timing signal flow and timing reference points

6.5 PDV measurement

In general, a packet delay variation (PDV) measurement involves comparing time instants on a sequence of packets, such as those of a packet timing signal, as they pass two points in the network. A configuration for performing such a measurement is shown in Figure 7 below. For each packet, a difference is computed between the time instant taken at the point of origin and the time instant taken at the point of destination.

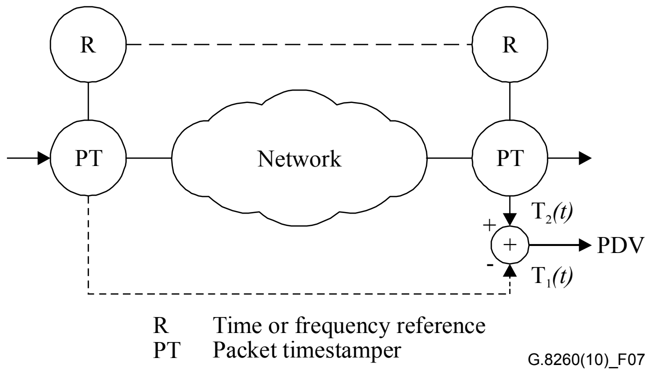

Figure 7 – Configuration for PDV measurement

An ideal configuration for making this measurement places two references traceable to a common time standard at each of the two measurement points. Such a configuration assesses not only the variation of packet delay, but also the packet transit time.

In many circumstances, such as packet-based frequency synchronization, the focus is on variation of packet delay rather than absolute packet delay. In such a case, frequency references can be employed for the references *R* and a common time reference is not required.

The use of unstable or inaccurate references directly impacts the PDV measurement, and may lead to limitations regarding the length of the PDV measurement. If the references are frequency standards, packet delay variation can be studied with the same precision as for the case where the references are time standards. If practical, a common frequency standard should be used for both *R* references. In other cases, separate primary reference clocks could be used.

The probe function could be implemented as separate equipment, or in the case where the first measurement point is at the source of the packet timing signal of interest, integrated into that equipment. In this case, the time instant could be delivered within the packet in the form of a timestamp. Similarly, in the case where the second measurement point is at the destination equipment, the probe function may be integrated into that equipment. Any inaccuracy of the timestamping function in the probes directly impacts the precision of the PDV measurement.

In the case where packets are sent according to a schedule that is known in advance, such as packets spaced by a uniform interval of time (e.g., CES), the relative origin timestamps are implicit, and the packet delay variation measurement can be performed with time stamping at the destination node.

Appendix I

Definitions and properties of packet measurement metrics

(This appendix does not form an integral part of this Recommendation)

NOTE – This appendix contains preliminary information related to ongoing studies on the definition of suitable PDV metrics. Since these studies are not finalized, the text below is for information only. It may be revised in a future version of the Recommendation, including potentially the removal of some parts of this text. It must by no means be used as normative text, be considered as definitive material, or as a specification of a packet slave clock implementation.

I.1 Introduction

With the telecommunications industry evolving and rapidly adopting packet technology, much emphasis has been placed on addressing packet synchronization and timing, including the use of measurement data to assist in specifying the performance of packet-based clocks.

Physical-layer timing signal stability quantities, including metrics such as MTIE and TDEV, have been used extensively and are central to synchronization measurement analysis. For a packet clock, the level of stability at the clock's packet network input has a direct bearing on the stability of the clock output. In terms of the packet metrics, the goal is to formulate packet-based stability quantities (metrics) that will provide a means of estimating the physical-based stability quantities for the packet clock output. This is illustrated in Figure I.1:

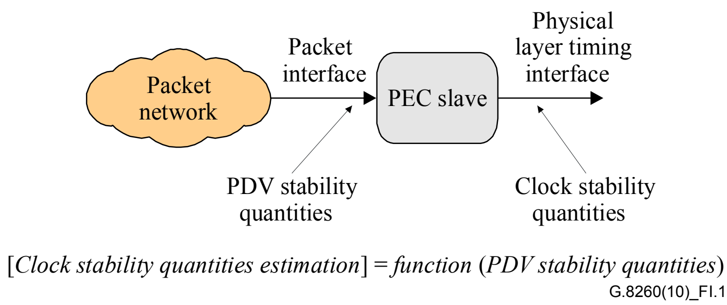

Figure I.1 – Packet equipment clock interfaces

PDV measurement guidelines are provided in clause 6.5.

For packet measurement data analysis, packet selection is added as an important component to the analysis. Indeed, in order to reduce the input PDV noise, the packet slave clock implementations are generally using only a subset of the received timing packets.

Therefore, a first simple approach to analyse the PDV as received by a packet slave clock can be to display the measured PDV in the form of a histogram. It generally provides useful information about the population of packets in different delay regions, and is in some cases sufficient to analyse the network conditions. Figure I.2 shows an example plot of the measured PDV and the corresponding histogram.

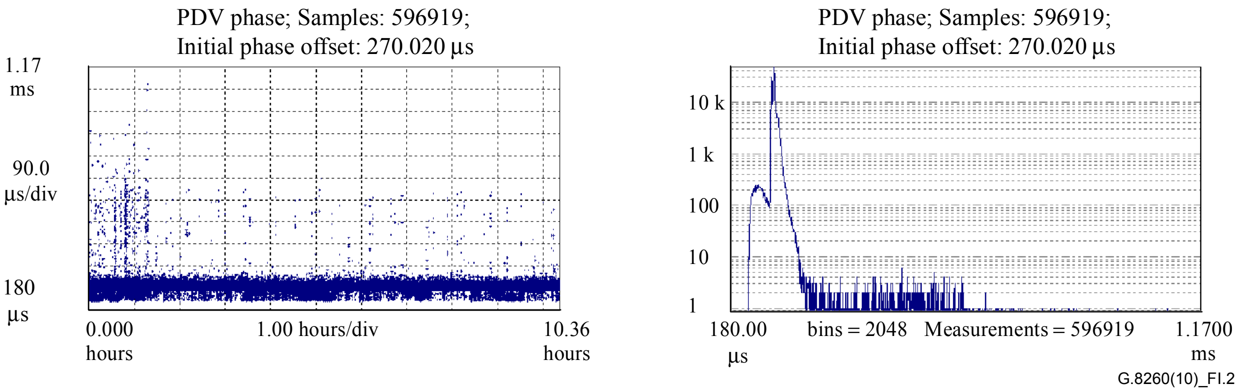

Figure I.2 – Measured packet delay and corresponding PDV histogram

In a second approach, mathematical tools (called "metrics" in this appendix) can be applied on a given PDV measurement to analyse it more in detail. Those metrics generally use only a subset of the packets. The packet selection can be either integrated into the calculation or performed as a preprocessing step. For example, the packet selection can focus on the minimum packet delay floor or more generally on some other region of packet delays.

With regard to the packet selection just discussed, it is important to point out the link between the methods of packet measurement data analysis described here and packet clock algorithms as they exist in actual equipment. For both, packet selection is important for optimization given the realities of packet delay variation.

However, it is important to mention that due to the proprietary nature of most of the packet slave clock implementations today, especially regarding the packet selection criteria, the packet selection used by a given PDV metric may not correspond to the criteria used in the packet slave clock of interest. Therefore, there can be some discrepancies between the information provided by a given PDV metric and the real performances achieved by a packet slave clock.

How to align the results provided by the PDV metrics and the performance of the packet slave clock is still under study. It may imply the specification of some minimum common behaviour in the packet selection criteria in the packet slave clock implementations.

While metrics can provide the basis for setting equipment requirements and network limits, their value as general analysis tools leading to insight into particular sets of measurement data should not be overlooked. For TDM synchronization measurements, normative limits have been applied to the MTIE and TDEV calculations, but other metrics such as ADEV and MDEV, while not associated with normative telecom limits, have great utility as analysis tools.

I.2 Definition of the time error sequence

For packet timing signals the packet time-error sequence can be established in the following way. For specificity, consider the transfer of timing packets originating at the packet master clock and terminating at the packet slave clock. In the case of PTP (see [IEEE 1588]) the rate of packets, f_0, is determined via negotiation between master and slave and can be as high as f_0 = 128 packets/s. PTP packets may not be equally spaced, but will meet this nominal rate over the long term. The ideal position in time for these packets is given by a timestamp embedded in the packet data.

Packets leave the master with a long-term mean spacing of $\tau_0 = 1/f_0$. From a signal processing perspective, the sampling rate is f_0 and an arbitrary mathematical-time origin for describing the times of departure from the master can be chosen. With this choice of time origin, the kth packet departs the master at time $t = k{\cdot}\tau_0$. In practice the kth packet will depart at time T_k which is but approximately equal to $k{\cdot}\tau_0$. Note that in the case of circuit emulation the times of departure are considered to be exactly spaced by τ_0. The kth packet then arrives at the slave at time S_k, where:

$$
\begin{aligned}
S_k &= T_k + \Delta + \varepsilon_k \\
e_k &= S_k - T_k
\end{aligned}
\qquad \text{(I-1)}
$$

where Δ is the reference transit delay time and ε_k is the transit delay time variation (i.e., packet delay variation or PDV). For the calculation of some PDV metrics, the operation may involve differencing and consequently the reference transit delay time, Δ, is moot since it is part of every term. Consequently, for purposes of calculating these PDV metrics, e_k can be used as the packet delay variation and be used interchangeably with ε_k. The same principle applies for packets that traverse the network from the slave to the master.

If the (hypothetical) packet time-error signal $x(t)$ is considered, then the sample of $x(t)$ taken at the sampling instant T_k is none other than e_k. That is, the sequence $\{e_k\}$ is equivalent to the packet time-error sequence but on a non-uniform time grid. The normal packet time-error sequence, $\{x_k\}$, is actually the sequence generated by sampling the packet time-error signal $x(t)$ on a uniform grid with sampling interval τ_0.

I.3 Packet selection

Physical layer timing signals are stationary and Gaussian in nature. Therefore, the relevant applied stability quantities (i.e., MTIE and TDEV) will usually use every noise sample point (significant instant) in the stability quantification process in order to filter out as much noise as possible and achieve the best stability quantification possible.

Packet-based timing signals, on the other hand, are not always stationary or Gaussian in nature. Hence, methods of quantifying them (thus attaining a better estimation of their ability to carry timing information) would usually require selecting only a subset of their entire population or in general performing some prefiltering before applying the specific stability quantification analysis. The following discussion focuses on the approach that involves a selection of packets.

I.3.1 Packet selection types

As mentioned above in the introduction, when applying some PDV metrics, packet selection can be incorporated into the calculation or into a preprocessing step. The packet selection techniques integrated into the calculation are useful in metrics that are intended to determine the fundamental limits set by the packet delay variation. On the other hand, preprocessing selects packets from suitable time window lengths. Therefore, the selection process resembles that of a practical packet clock in steady state operation.

I.3.1.1 Preprocessed packet selection

With preprocessed packet selection, quantifying packet timing signals is carried in two steps:

1) Applying a specific packet selection procedure to select a specific subset of PDV noise samples, having similar delay properties, among the entire population of PDV noise samples.
2) Applying the required stability quantification algorithm (metric) over the selected group of samples to get an estimation of the achievable output clock quality estimation.

   NOTE – As mentioned earlier, there can be some discrepancies between the information provided by a given PDV metric and the real performances achieved by a packet slave clock.

This is shown in Figure I.3:

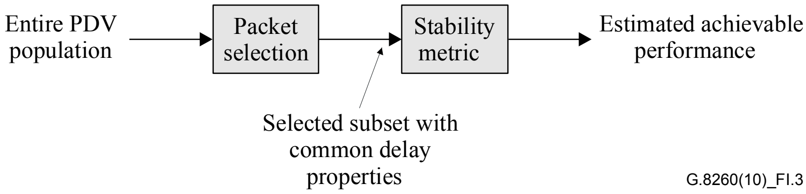

Figure I.3 – Preprocessed packet selection

In essence, an input packet time-error sequence *x(t)* is subject to packet selection which produces a new packet time-error sequence *x′(t)*. In the case of preprocessed packet selection, the preliminary packet selection process is independent of the applied stability quantification. Thus, different combinations of the two might yield interesting properties and need to be looked into. Both need to be fully defined as each has significant influence on the resulting performance measurement.

I.3.1.2 Integrated packet selection

With integrated packet selection, the packet selection is integrated into the metric calculation, as shown in Figure I.4. Generally this involves replacing a full population averaging calculation with a selection process that may or may not itself include averaging.

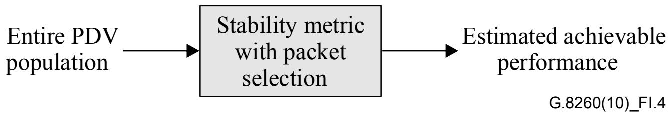

Figure I.4 – Integrated packet selection

NOTE – As mentioned earlier, there can be some discrepancies between the information provided by a given PDV metric and the real performances achieved by a packet slave clock.

I.3.2 Packet selection methods

Four examples of packet selection methods are described in the clauses that follow. The first two, minimum packet selection and percentile packet selection, focus on packet data at the floor. The second two, band packet selection and cluster range packet selection, can be applied either at the floor or at some other region.

I.3.2.1 Minimum packet selection method

The minimum packet selection method involves selecting a minimum within a section of data. This can be represented as follows:

$$x_{\min}(i) = \min\lfloor x_j \rfloor for(i <= j <= i + n - 1) \quad \text{(I-2)}$$

I.3.2.2 Percentile packet selection method

The percentile packet selection method is related to the minimum packet selection method, except that instead of selecting the minimum, some number (or some percentage) of minimum values are chosen and averaged together. It is a special case of the band packet selection method described below with the lower index set to zero.

I.3.2.3 Band packet selection method

The band packet selection method can be used to select a section of packet data at the floor or from some other region such as the ceiling or somewhere else above the floor. To perform the band packet selection, it is first necessary to represent the sorted packet time-error sequence. Let "x'" represent this sorted phase sequence from minimum to maximum over the range $i \leq j \leq i + n - 1$.

Next, it is necessary to represent the indices which are themselves set based on the selection of two percentile levels.

Let "a" and "b" represent indices for the two selected percentile levels. The averaging is then applied to the "x'" variable indexed by "a" and "b". The number of averaged points "m" is related to "a" and "b": $m = b - a + 1$.

$$x'_{band\_mean}(i) = \frac{1}{m}\sum_{j=a}^{b} x'_{j+i} \qquad \text{(I-3)}$$

A percentile level is selected by using rounding to find the closest index from the desired percentile value. The additional constraint is that the index value has a minimum of the first index and a maximum of the last index. Thus, for example, a set of ten points with a percentile set to 2% (0.02) would be set to the minimum index so that at least a single point would be selected.

I.3.2.4 Cluster range packet selection method

The cluster range packet selection method uses a time/phase-bounded range rather than indices based on percentiles (probabilities) to perform the packet selection. This selection method involves the selection of a group of one or more packets which are closely related with respect to their transit time. The location of the cluster may be made based on various criteria, for example, packets at the floor or from some other region observed in the window interval, or the location of the cluster may be based on other criteria or information outside the interval. The cluster of packets could then be processed in a variety of ways to generate a single value for that interval, such as the mean transit time of all packets within the cluster.

Figure I.5 shows an example packet delay sequence, zooming in on an example of a packet cluster for a single window interval.

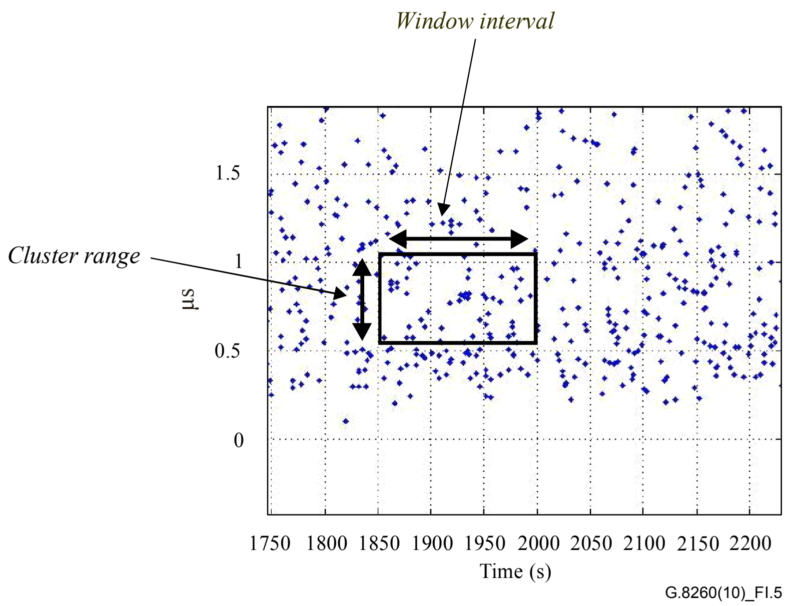

Figure I.5 – Example of concept of cluster range packet selection

I.3.3 Consideration of non-stationary network conditions

As the packet selection can focus on a particular statistical region, it is important to consider the case where network packet delay statistics are not stationary, but rather change over time. For example, if a floor-based metric is applied to packet measurement data where the floor shifts, the application of the floor-based metric would perhaps be best applied to sections of the data separately (see Figures I.6 and I.7). In many cases, segregating the data into sections might not be so straightforward, such as the case of an increasing load ramp. Such a situation is for further study.

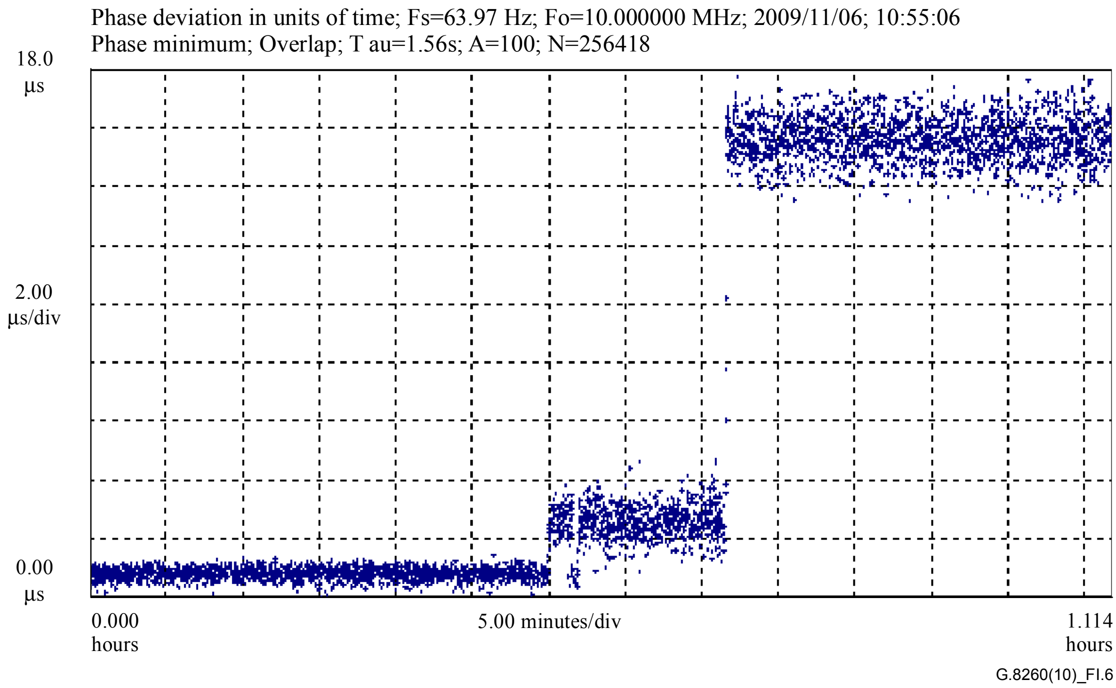

Figure I.6 – Minimum tracking statistic shows three distinct sections

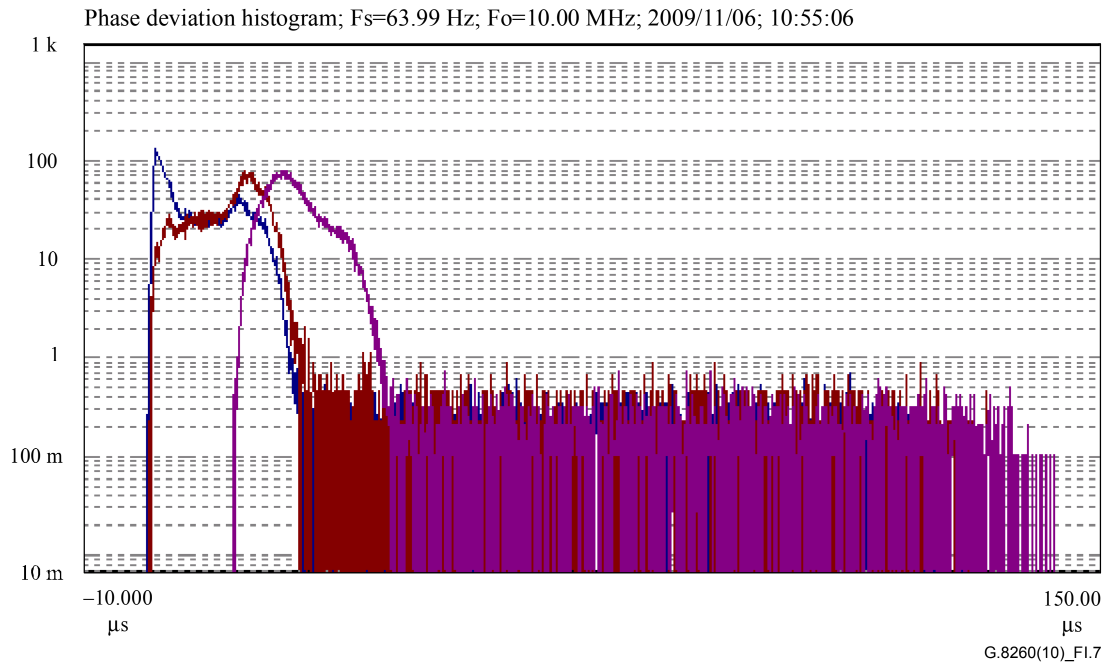

Figure I.7 – Histograms (PDFs) for the three sections

I.4 PDV metrics

The definition of metrics for characterizing PDV is for further study.

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Printed in Switzerland
Geneva, 2010