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

Packet over Transport aspects – Synchronization, quality and availability targets

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet protocol aspects – Transport

Network limits for time synchronization in packet networks with partial timing support from the network

Recommendation ITU-T G.8271.2/Y.1366.2

International Telecommunication Union

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Recommendation ITU-T G.8271.2/Y.1366.2

Network limits for time synchronization in packet networks with partial timing support from the network

Summary

Recommendation ITU-T G.8271.2/Y.1366.2 specifies the maximum network limits of phase and time error that shall not be exceeded. It specifies the minimum equipment tolerance to phase and time error that shall be provided at the boundary of these packet networks at phase and time synchronization interfaces. It also outlines the minimum requirements for the synchronization function of network elements.

Recommendation ITU-T G.8271.2/Y.1366.2 addresses the case of time and phase distribution across a network with packet-based method with partial timing support to the protocol level from the network.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.8271.2/Y.1366.2	2017-08-13	15	11.1002/1000/13324

Keywords

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The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

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Recommendation ITU-T G.8271.2/Y.1366.2

Network limits for time synchronization in packet networks with partial timing support from the network

1 Scope

This Recommendation specifies the maximum network limits of phase and time error that shall not be exceeded. It specifies the minimum equipment tolerance to phase and time error that shall be provided at the boundary of these packet networks at phase and time synchronization interfaces. It also outlines the minimum requirements for the synchronization function of network elements.

This Recommendation addresses the distribution of time and phase across a network, using the packet-based method with partial timing support to the protocol level from the network. In particular, it applies to the assisted partial timing support (APTS) and partial timing support (PTS) architectures described in [ITU-T G.8275] and the precision time protocol (PTP) profile defined in [ITU-T G.8275.2].

This Recommendation addresses the following cases.

1) Assisted partial timing support (APTS).

   In the APTS configuration, PTP is used as a backup timing source to a local time reference (e.g., primary reference time clock (PRTC) based on the global navigation satellite system (GNSS)) for durations up to 72 h. It is not intended to use PTP as the primary timing source.

   Network requirements take into consideration the dynamic time error (dTE) generated by the network.

2) Partial timing support from the network (PTS).

   In the PTS configuration, PTP is used as the primary source of time to the end application. In this mode, a local time reference (e.g., GNSS) is not available.

   Network requirements take into consideration the combination of both the constant time error (cTE) and dTE components generated by the network.

A network that is based on the architecture defined in [ITU-T G.8265], and is designed to meet the network limits for frequency defined in [ITU-T G.8261.1], is not designed for the delivery of accurate time or phase, which requires much lower levels of packet delay variation (PDV) and asymmetry. The network limits specified in this document are for small, well-controlled networks (e.g., in-building or last-mile network segments), which can guarantee that the stringent PDV and asymmetry network limits are met. Further guidance can be found in Appendix II.

The necessary clock specifications are for further study.

The packet networks that are in the scope of this Recommendation are currently limited to the following types:

– Ethernet: [IEEE 802.3] and [IEEE 802.1Q]
– Multiprotocol label switching (MPLS): [IETF RFC 3031] and [ITU-T G.8110]
– Internet protocol (IP): [IETF RFC 791] and [IETF RFC 2460]

The use of other network types are for further study.

The physical layer that is relevant to this specification is the Ethernet media types as defined in [IEEE 802.3].

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.8110] Recommendation ITU-T G.8110/Y.1370 (2005), *MPLS layer network architecture*.

[ITU-T G.8260] Recommendation ITU-T G.8260 (2015), *Definitions and terminology for synchronization in packet networks*.

[ITU-T G.8261.1] Recommendation ITU-T G.8261.1/Y.1361.1 (2012), *Packet delay variation network limits applicable to packet-based methods (Frequency synchronization).*

[ITU-T G.8265] Recommendation ITU-T G.8265/Y.1365 (2010), *Architecture and requirements for packet-based frequency delivery*.

[ITU-T G.8271] Recommendation ITU-T G.8271/Y.1366 (2016), *Time and phase synchronization aspects of packet networks*.

[ITU-T G.8271.1] Recommendation ITU-T G.8271.1/Y.1366.1 (2013), *Network limits for time synchronization in packet networks*.

[ITU-T G.8272] Recommendation ITU-T G.8272/Y.1367 (2015), *Timing characteristics of primary reference time clocks*.

[ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2017), *Architecture and requirements for packet-based time and phase distribution*.

[ITU-T G.8275.1] Recommendation ITU-T G.8275.1/Y.1369.1 (2016), *Precision time protocol telecom profile for phase/time synchronization with full timing support from the network*

[ITU-T G.8275.2] Recommendation ITU-T G.8275.2/Y.1369.2 (2016), *Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network*.

[IEEE 802.1Q] IEEE 802.1Q-2014, *IEEE Standard for local and metropolitan area networks – Bridges and bridged networks*.

[IEEE 802.3] IEEE 802.3-2015, *IEEE Standard for Ethernet* .

[IEEE 1588-2008] IEEE 1588-2008, *IEEE Standard for a precision clock synchronization protocol for networked measurement and control systems*.

[IETF RFC 791] IETF RFC 791 (1981), *Internet protocol (IP)*.

[IETF RFC 2460] IETF RFC 2460 (1998), *Internet Protocol, Version 6 (IPv6) – Specification*.

[IETF RFC 3031] IETF RFC 3031 (2001), *Multiprotocol label switching architecture*.

3 Definitions

The terms and definitions used in this Recommendation are contained in [ITU-T G.810] and [ITU-T G.8260]

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APTS Assisted Partial Timing Support

cTE constant Time Error

dTE dynamic Time Error

GNSS Global Navigation Satellite System

IWF Interworking Function

MPLS Multiprotocol Label Switching

PDV Packet Delay Variation

PRC Primary Reference Clock

PRS Primary Reference Source

PRTC Primary Reference Time Clock

PTP Precision Time Protocol

PTS Partial Timing Support

T-BC Telecom Boundary Clock

T-BC-P Telecom Boundary Clock – Partial support

T-GM Telecom Grandmaster

TLV Type Length Variable

T-TSC Telecom Time Slave Clock

T-TSC-A Telecom Time Slave Clock – Assisted

T-TSC-P Telecom Time Slave Clock – Partial support

5 Conventions

Within this Recommendation, the following conventions are used: the term PTP refers to the protocol defined in [IEEE 1588-2008].

The term telecom boundary clock – partial support (T-BC-P) is a device consisting of a boundary clock as defined in [IEEE 1588-2008], with only PTS at the protocol level from the network, and with additional performance characteristics for further study.

The term telecom time slave clock – assisted (T-TSC-A) (e.g., by GNSS) is a device consisting of a PTP slave only ordinary clock as defined in [IEEE 1588-2008], assisted by a local time reference clock device, and with additional performance characteristics for further study.

The term telecom time slave clock – partial (T-TSC-P) is a device consisting of a PTP slave only ordinary clock as defined in [IEEE 1588-2008], with only PTS at the protocol level from the network, and with additional performance characteristics for further study.

The terms "dTE" and "time noise" are used interchangeably throughout this Recommendation to indicate jitter and wander components of the timing signal.

6 Network reference model

The general network reference model is described in [ITU-T G.8271].

7 Packet network limits

This clause defines the network limits that apply to the packet network, i.e., reference points A, B and C in Figures 1 and 2.

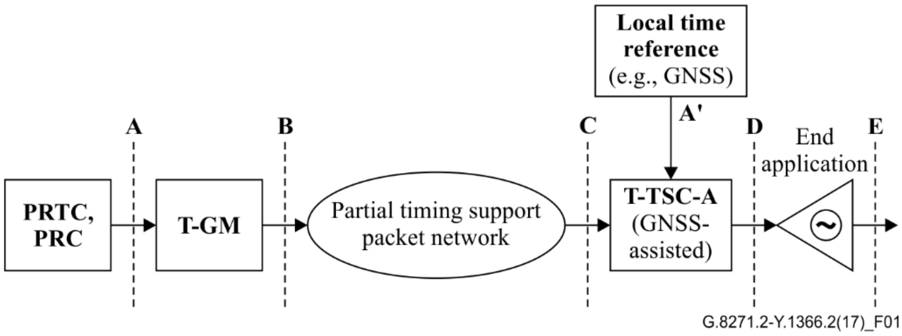

Figure 1 – Reference model for network limits for assisted partial timing support

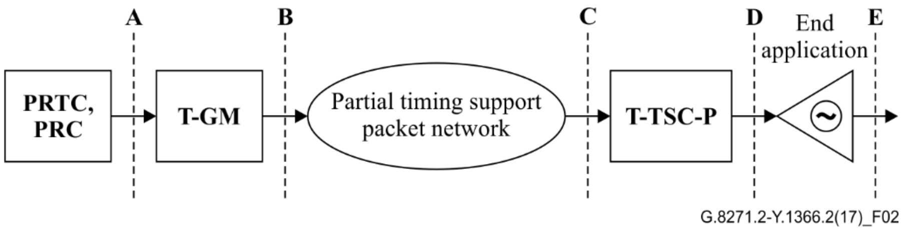

Figure 2 – Reference model for network limits for partial timing support

The two examples in Figures 1 and 2 are simplified. They represent use cases 1a and 1b in Appendix I. It is highlighted in Appendix I that in some deployment cases, the part of the network located between point C and D may contribute significantly to the total time error budget. In these cases, the network limits apply to point D.

7.1 Network limits at reference point A and A'

The network limits applicable at reference points A and A′, i.e., at the output of the PRTC, are defined in [ITU-T G.8272]. In particular, according to [ITU-T G.8272] the maximum absolute time error is:

$$\max|TE| \leq 100 \text{ ns}$$

NOTE 1 – This limit is applicable under normal, locked operating conditions. The limit under failure conditions at the PRTC is for further study.

NOTE 2 – The network limit at point A′ may not be applicable in all cases.

The dTE network limits applicable at the reference points A and A′ are specified in clause 6.1 of [ITU-T G.8272].

7.2 Network limit at reference point B

In the case of a telecom grandmaster (T-GM) integrated in the PRTC, the network limit applicable at reference point B is the same as the limit applicable at reference point A.

In the case of a T-GM external to the PRTC, the network limit applicable at reference point B is for further study.

7.3 Network limits at reference point C

7.3.1 Packet network limits for assisted partial timing support

The limits given in this clause represent the maximum permissible levels of phase/time error and noise, at interfaces within a packet network in charge of distributing phase/time synchronization per the applications corresponding to the class 4 listed in Table 1 of [ITU-T G.8271].

The limits applicable to other classes at the reference point C are for further study.

Two types of network limit are defined. Type I places less stringent requirements on the dTE generated by the network, but requires a correspondingly higher performance from the clock, while type II places more stringent requirements on the dTE generated by the network with a lower performance clock.

The limits given below shall be met for all operating conditions (except during PTP rearrangements), regardless of the amount of equipment preceding the interface. In general, these network limits are compatible with the minimum tolerance to time error and noise that all equipment input ports are required to provide.

The network limit is defined in terms of the peak-to-peak value of pktSelected2wayTE (see Appendix I of [ITU-T G.8260]).

Considering the peak-to-peak value of pktSelected2wayTE as the limit makes sure that whatever the instantaneous value of pktSelected2wayTE when GNSS source is lost, the absolute TE will remain within expected limits (either positive or negative) while PTP is the selected fall-back source.

Any transient associated with switching from the local time reference to PTP and back is for further study.

NOTE – See Appendix III for considerations on maintaining time with frequency.

7.3.1.1 Type I network limit

The network limit value and the metric processing parameters that apply for a type I network are as follows:

– Peak-to-peak pktSelected2wayTE <1 100 ns

– Selection window = 200 s

– Selection percentage = 0.25%

The network limit calculation method implies that the Sync and Delay_req packet rate must be at least 2 packets/s, in order to receive a valid packet in every selection window. However, the network limit might only be met by using a packet rate higher than 2 packets/s. For proper operation, the slave clock should use a packet rate that is at least as high as the packet rate required for the network limit to be satisfied. It is not expected that any slave clock will meet the relevant target performance requirements at lower packet rates. The appropriate packet rate used by the clocks in the network depends on the clock characteristics and on the target performance requirements.

7.3.1.2 Type II network limit

The network limit value and the metric processing parameters that apply for a type II network are for further study.

7.3.2 Packet network limits for PTS

The limits given in this clause represent the maximum permissible levels of phase/time error and noise, at interfaces within a packet network in charge of distributing phase/time synchronization per the applications corresponding to the class 4 listing in Table 1 of [ITU-T G.8271].

The limits applicable to other classes at reference point C are for further study.

Two types of network limit are defined. Type I places less stringent requirements on the dTE generated by the network, but requires a correspondingly higher performance from the clock, while type II places more stringent requirements on the dTE generated by the network with a lower performance clock.

The limits given in clauses 7.3.2.1 and 7.3.2.2 shall be met for all operating conditions (except during PTP rearrangements), regardless of the amount of equipment preceding the interface. In general, these network limits are compatible with the minimum tolerance to time error and noise that all equipment input ports are required to provide.

The network limit is defined in terms of the maximum absolute value of pktSelected2wayTE (max|pktSelected2wayTE|) (see Appendix I of [ITU-T G.8260]).

7.3.2.1 Type I network limit

The network limit value and the metric processing parameters that apply for a type I network are as follows:

– max|pktSelected2wayTE| < 1 100 ns

– Selection window = 200 s

– Selection percentage = 0.25%

7.3.2.2 Type II network limit

The network limit value and the metric processing parameters that apply for a type II network are for further study.

Appendix I

Deployment scenarios for partial timing support networks

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

Clauses I.1 to I.5 illustrate some of the example deployment scenarios that might use the PTS and APTS architectures. It is expected that it will not be possible to meet strict timing requirements with all of these deployment scenarios.

I.1 Assisted partial and partial timing support network use cases

The first scenario, labelled deployment case 1a, represents an APTS network. See Figure I.1. The T-TSC-A has available a local time reference (e.g., a PRTC or GNSS-based time source). The T-TSC-A would give preference to using that time source for synchronization. The T-TSC-A would use the PTP timing packets as a secondary time or frequency source for synchronization in the case of failure of the local time reference. This scenario is the one documented in clause 7.

In each of Figures I.1 to I.4, a T-BC-P is shown in the middle of the packet network between the T-GM and the T-TSC-A or T-TSC-P. This is optional, but may prove useful to reduce noise accumulation in the PTP timing flow. The use of the T-BC-P and its impact on the performance budget is for further study.

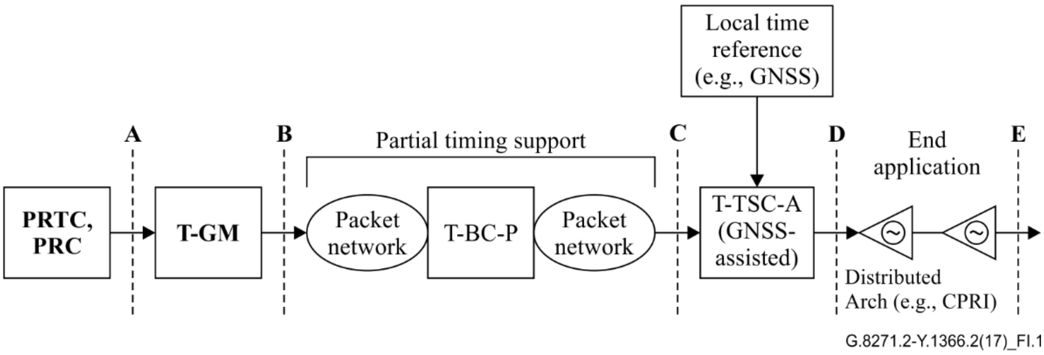

Figure I.1 – Deployment case 1a

In some instances, the slave clock and the local time reference may be integrated within the end application. In that case, the network limit for reference point C will apply at the input to the end application, and reference point D may not be externally accessible.

The second scenario, labelled deployment case 1b, represents a PTS network. See Figure I.2. The operator's time source information is provided (at interface A) using a PRTC, perhaps in conjunction with a primary reference clock (PRC) or primary reference source (PRS). The timing information is sent into the PTP domain using a T-GM (at interface B). The PTP domain operates according to the [ITU-T G.8275.2] telecom profile for time/phase synchronization and contains a packet network consisting of a limited number of unaware network elements (switches/routers) and T-BC-Ps. The PTP timing information is terminated (at interface C) by a T-TSC-P and the time information is connected to the end application (at interface D).

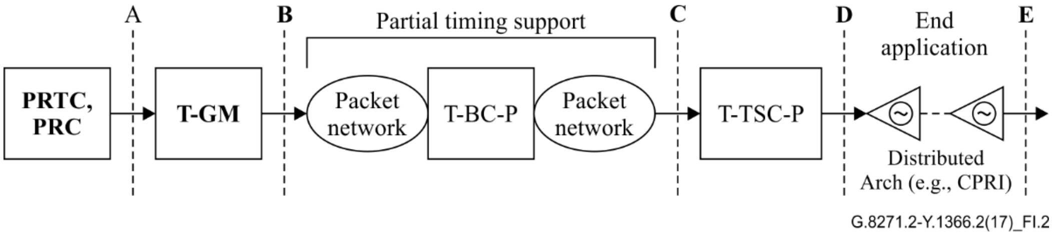

Figure I.2 – Deployment case 1b

If the slave clock is integrated within the end application, the network limit for reference point C will apply at the input to the end application, and reference point D may not be externally accessible.

I.2 Full timing support network followed by an assisted partial timing support network or partial timing support network

In some instances, a full timing support network (refer to [ITU-T G.8271.1]) may be deployed after the T-GM (e.g., in the core or metro network) and a PTS network may be deployed closer to the end application (in the metro or access network). This may be the case in both the APTS and PTS architectures.

The APTS case is illustrated in deployment case 2a. See Figure I.3. In this scenario, while the network limit at reference point C may be the same as scenario 1a, some time error budget must be allocated to the portion of the network that is full timing support (between interface B and B′). The allocation of budget to each of the network sections is for further study.

An interworking function (IWF), containing a telecom boundary clock (T-BC) among other functions, would be needed to translate from the full timing support profile ([ITU-T G.8275.1]) to the PTS profile ([ITU-T G.8275.2]) going downstream from the T-GM towards the end application.

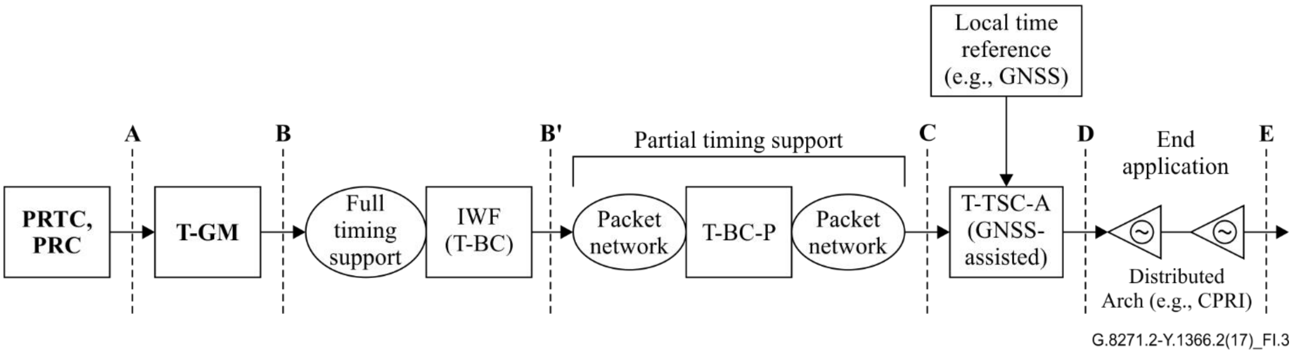

Figure I.3 – Deployment case 2a

As noted above, the telecom time slave clock (T-TSC) and local time reference may be integrated into the end application, in which case reference point C occurs at the input to the end application and reference point D may not be externally accessible.

Likewise this mixture of full timing support networks and PTS networks may occur with a PTS network, as illustrated in deployment case 2b. See Figure I.4.

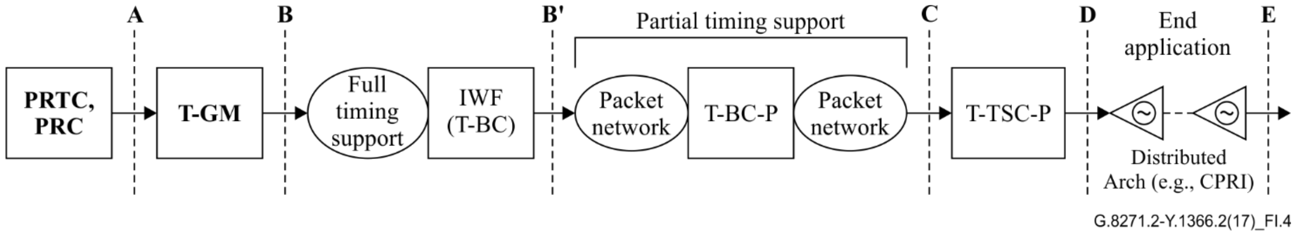

Figure I.4 – Deployment case 2b

I.3 Partial timing support network followed by a full timing support network

In some instances, an APTS or PTS network may be deployed after the T-GM (e.g., in the core or metro network) and a full timing support network may be deployed closer to the end application (in the metro or access network). The network limits and time error budgets associated with each section of the network are for further study.

An interworking function (IWF) , containing a T-BC-P among other functions, would be needed to translate from the PTS profile ([ITU-T G.8275.2]) to the full timing support profile ([ITU-T G.8275.1]) going downstream from the T-GM towards the end application.

I.4 Assisted partial timing support network followed by a partial timing support network

In some instances, an APTS network may be deployed after the T-GM (e.g., in the core or metro network), with a small section using PTS closer to the end application (in the access or last mile network). A T-BC-P assisted by a local time reference (e.g., a PRTC or GNSS time source) would be required between the two network segments.

In this scenario, some time error budget must be allocated to the portion of the network following the time-assisted network element. The network limits and time error budgets associated with each section of the network are for further study.

I.5 Use of partial timing support network to bridge between two full timing support networks

In some circumstances, an operator deploying a full timing support architecture has to connect two network segments over a PTP-unaware network segment owned or operated by a third party operator. In this case, it may be necessary to use PTS across the third party network. The network limits and time error budgets associated with each section of the network are for further study.

An interworking function (IWF), containing a T-BC among other functions, would be needed to translate from the full timing support profile ([ITU-T G.8275.1]) to the PTS ([ITU-T G.8275.2]) going downstream from the T-GM towards the end application.

A second interworking function (IWF), containing a T-BC-P among other functions, would be needed to translate from the PTS profile ([ITU-T G.8275.2]) back to the full timing support ([ITU-T G.8275.1]) going downstream from the T-GM towards the end application.

Appendix II

Considerations for handling precision time protocol traffic in networks with partial timing support

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

In order to meet the stringent network limits specified in this Recommendation, careful planning is needed in order to control the PDV and delay asymmetry generated by the network. Such a controlled network would typically be a small scale, local network (e.g., in-building or "last-mile" network segments, such as might be used for connection of small cells).

I1.1 Network aspects

The following aspects should be considered.

1) The asymmetry and PDV generated by the network elements under applicable conditions should be characterized and validated. Such conditions should include:
   a) dynamic traffic load and frame lengths;
   b) network congestion;
   c) link failure and restoration;
   d) network element power cycle;
   e) network reroute of PTP packets.
2) It is recommended that PTP messages be assigned to a high quality of service in order to reduce the PDV created by other data carried over the network.
3) The link technology should not create excessive asymmetry or PDV.
4) Where possible, interface rate changes should be signalled by use of the INTERFACE_RATE type length variable (TLV) defined in Annex D of [ITU-T G.8275.2]. This allows the delay asymmetry caused by the rate change to be compensated for. If the equipment does not support the INTERFACE_RATE TLV, the effect of the asymmetry must be carefully considered.
5) The use of boundary clocks at key locations may be useful to reduce the accumulation of PDV. This is for further study.

The network should be based on a very small number of PTP unaware network elements. The number is strongly related to the specific network equipment, the transport technology, and the management and control of the traffic load in the network. It should be noted that not all switching and routing technology is the same, and this can affect the level of PDV and delay asymmetry produced. Switches and routers have their own specific characteristics depending on their internal implementation. Some more complex network elements generate higher levels of PDV and asymmetry than smaller ones.

Some trials have reported successful operation over three to five PTP-unaware network elements where the traffic load and asymmetry were well controlled; other trials have reported poor performance even over one PTP-unaware network element. Depending on the specific characteristics of the network elements used, and the traffic load within the network, the network may not support time or phase synchronization using PTS.

In addition, conditions in a network may change over time, e.g., as traffic load changes or as network asymmetry changes (e.g., this may occur in some technologies such as optical transport network). Therefore one single measurement is not sufficient to fully characterize a network. Network monitoring is recommended to ensure the network limits are consistently met.

I1.2 Time error performance aspects

For APTS networks, it is the dTE created by the PDV in the network that is of interest. Constant time error (cTE) created by delay asymmetry in the network should be sufficiently stable, relative to the required performance. If this is met, the local time reference of the T-TSC-A may be used to compensate for the asymmetry created by the network. Compensation may be achieved by either:

1) measuring the delay asymmetry while the local time reference is in operation, such that it is known in advance if the local time reference fails;

2) setting the correct time while the local time reference is in operation, and using the PTP flow as a source of frequency to maintain the time base when the local time reference is out of service.

For PTS networks, the full time error created by the network is important, including both the cTE and dTE components. This is because there is no local time reference to compensate for the network delay asymmetry.

Appendix III

The use of frequency to maintain precise time

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

Frequency, which can be used to hold precise time, can be derived from PTP. Further, in the case of PTP derived frequency, it is possible to derive frequency using packets from a single direction. Thus, for frequency from PTP, three approaches are possible:

1) use of the forward sequence;

2) use of the reverse sequence;

3) use of both forward and reverse sequences together.

In cases where one of the two sequences shows much less PDV than the other, focus on that sequence rather than both is warranted. Such a situation is illustrated in Figure III.1.

The limits for APTS are based on a peak-to-peak value of pktSelected2WayTE. In Appendix I of [ITU-T G.8260], the pktSelected2WayTE, expressed as $x_c'(t)$, is described by Figure III.1.

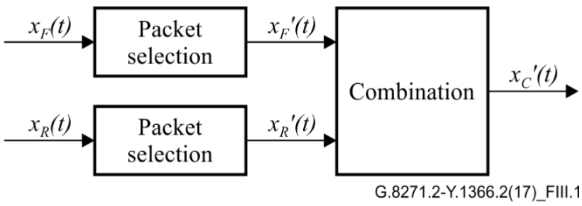

Figure III.1 – Packet Selection

Note that the packet selection is done independently on each one-way sequence with the results combined in each selection window. Thus the forward and reverse sequences are *both* constrained at the same time for each window.

For APTS, time is normally supplied by GNSS, and in the event of GNSS loss turns to PTP to provide or hold time. Time can be maintained by stable frequency, particularly over short periods of time such as small multiples of the 100 s or 200 s selection windows described above. The source of stable frequency might be an internal oscillator in the APTS clock, a traceable frequency input such as from SyncE, or a frequency derived from PTP.

The ability of a local oscillator to hold time is illustrated in Table III.1.

Table III.1 – Local oscillator types and phase drift

	10 ns	**50 ns**	**100 ns**	**500 ns**	**1 µs**
ITU-T G.812 Type 1	0.22 h	0.50 h	0.70 h	1.57 h	2.22 h
ITU-T G.812 Type 2	1.15 h	2.58 h	3.65 h	8.16 h	11.55 h
ITU-T G.812 Type 4	0.11 h	0.24 h	0.33 h	0.75 h	1.05 h
ITU-T G.812 Type 4	1.11 min	2.48 min	3.51 min	7.84 min	11.09 min
ITU-T G.812 Type 5	0.30 h	0.67 h	0.94 h	2.11 h	2.98 h
ITU-T G.812 Type 6	4.00 min	8.94 min	12.65 min	28.28 min	40.00 min
ITU-T Opt 1	0.49 min	1.10 min	1.55 min	3.46 min	4.90 min
ITU-T Opt 2	0.32 min	0.72 min	1.02 min	2.28 min	3.23 min

The ability of a traceable frequency to hold time is illustrated in Table III.2.

Table III.2 – Traceable frequency phase drift

	10 ns	50 ns	100 ns	1 µs	10 µs
Celsium (1E-12)	2.8 h	13.9 h	27.8 h	11.6 days	115.7 days
ITU-T G.811 (1E-11)	16.7 min	1.4 h	2.8 h	1.2 days	11.6 days

In the case of frequency derived from PTP, there are fairly common situations where stable frequency can be easily attained from PTP, though precise time is attained with greater difficulty. Such a situation is exemplified by Figure III.2, where blue shows the forward packet sequence and red shows the reverse packet sequence:

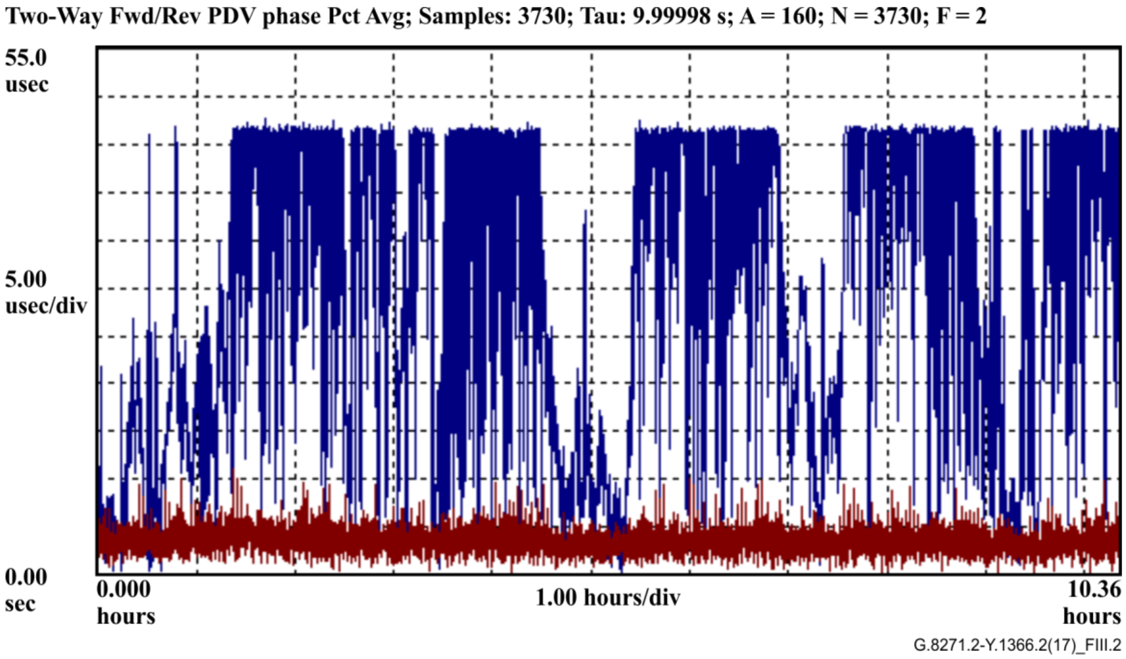

Figure III.2 – Examples of forward and reverse packet sequences

In this case, focusing on the reverse packets would yield a better frequency result.

Further, there are times when the forward sequence is advantageous for holding time and other times, perhaps just a short time later, when the reverse sequence is advantageous for holding time. Perhaps in a series of 10 selection windows, 1-3 are better for forward, 4-7 better for reverse, and 8-10 better for forward.

Thus, while the limit based on peak-to-peak pktSelected2WayTE can suitably guarantee the presence of network conditions for APTS devices to deliver proper synchronization, a single one-way sequence can provide a stable frequency that can be used to assist in holding precise time.

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