

Recommendation

ITU-T G.8273/Y.1368 (06/2023)

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

Framework of phase and time clocks

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Transmission systems and media, digital systems and networks

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Recommendation ITU-T G.8273/Y.1368

Framework of phase and time clocks

Summary

Recommendation ITU-T G.8273/Y.1368 is a framework Recommendation for phase and time clocks for devices used in synchronizing network equipment that operates in the network architecture specified in Recommendations ITU-T G.8271, ITU-T G.8275 and the ITU-T G.8271.x-series of Recommendations.

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Recommendation ITU-T G.8273/Y.1368

Framework of phase and time clocks

1 Scope

This Recommendation is a framework Recommendation for phase and time clocks for devices used in synchronizing network equipment that operate in the network architecture specified in [ITU-T G.8271], [ITU-T G.8275] and the ITU-T G.8271.x-series of Recommendations.

This Recommendation serves as a framework for phase and time clocks specified in the ITU-T G.8273.x-series, and includes annexes specifying methods of their testing and measurement.

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.8260] Recommendation ITU-T G.8260 (2022), *Definitions and terminology for synchronization in packet networks*.
- [ITU-T G.8271] Recommendation ITU-T G.8271/Y.1366 (2020), *Time and phase synchronization aspects of telecommunication networks*.
- [ITU-T G.8272] Recommendation ITU-T G.8272/Y.1367 (2018), *Timing characteristics of primary reference time clocks*.
- [ITU-T G.8272.1] Recommendation ITU-T G.8272.1/Y.1367.1 (2016), *Timing characteristics of enhanced primary reference time clocks*.
- [ITU-T G.8273.2] Recommendation ITU-T G.8273.2/Y.1368.2 (2023), *Timing characteristics of telecom boundary clocks and telecom time synchronous clocks for use with full timing support from the network*.
- [ITU-T G.8273.3] Recommendation ITU-T G.8273.3/Y.1368.3 (2020), *Timing characteristics of telecom transparent clocks for use with full timing support from the network*.
- [ITU-T G.8273.4] Recommendation ITU-T G.8273.4/Y.1368.4 (2020), *Timing characteristics of telecom boundary clocks and telecom time slave clocks for use with partial timing support from the network*.
- [ITU-T G.8275] Recommendation ITU-T G.8275/Y.1369 (2020), *Architecture and requirements for packet-based time and phase distribution*.
- [IEEE 1588] Either [IEEE 1588-2008] or [IEEE 1588-2019] depending on the specific implementation. See clause 5 for more details.
- [IEEE 1588-2008] IEEE Std 1588-2008, *IEEE Standard for a precision clock synchronization protocol for networked measurement and control systems*.
- [IEEE 1588-2019] IEEE Std 1588-2019, *IEEE Standard for a precision clock synchronization protocol for networked measurement and control systems*.

3 Definitions

Definitions related to synchronization are contained in [ITU-T G.810] and [ITU-T G.8260].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

1 PPS	1 Pulse Per Second
cTE	constant Time Error
dTE	dynamic Time Error
DUT	Device Under Test
EEC	Ethernet Equipment Clock
eEEC	enhanced synchronous Ethernet Equipment Clock
ESMC	Ethernet Synchronization Message Channel
eSyncE	enhanced Synchronous Ethernet
GM	Grandmaster
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
LO	Local Oscillator
MTIE	Maximum Time Interval Error
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
QL	Quality Level
SUT	System Under Test
SyncE	Synchronous Ethernet
T-BC	Telecom Boundary Clock
TDEV	Time Deviation
T-GM	Telecom Grandmaster
ToD	Time of Day
TR	Time Receiver
TT	Time Transmitter
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Synchronous Clock

5 Conventions

Within this Recommendation, the following conventions are used: the term precision time protocol (PTP) refers to that defined in [IEEE 1588].

Within this Recommendation, some requirements are stated as requiring compliance to [IEEE 1588]. For implementations based on [IEEE 1588-2008], reference to [IEEE 1588] means compliance with

the 2008 edition. For implementations based on [IEEE 1588-2019], reference to [IEEE 1588] means compliance with the 2019 edition.

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

6 General introduction of phase and time clocks

This Recommendation serves as a framework for phase and time clocks that have been specified or are to be so in the ITU-T G.8273.x-series of Recommendations.

The focus of this Recommendation is on packet-based methods for transferring time or phase. Specific methods based on the PTP [IEEE 1588] are considered.

The ITU-T G.8273.x-series of Recommendations specifies the items in the following list. However, it is important to note that as of the date of publication, ITU-T G.8273.1 has not yet been approved; its specifications are still under study and thus may be subject to change.

- Telecom grandmaster (T-GM) specification. The T-GM is a device consisting of a GM as defined in [IEEE 1588-2008] with additional performance characteristics. The details of T-GM are specified in [ITU-T G.8272]. Other types of T-GM are expected to be specified in ITU-T G.8273.1 (currently under study).
- Telecom boundary clock (T-BC) specification. The T-BC is a device consisting of a boundary clock as specified in [IEEE 1588-2008] with additional performance characteristics such as noise generation, noise tolerance, noise transfer, transient response and holdover. [ITU-T G.8273.2] specifies T-BC.
- Telecom transparent clock (T-TC) specification. The T-TC is a device consisting of a transparent clock as specified in [IEEE 1588-2008] with additional performance characteristics. [ITU-T G.8273.3] specifies T-TC.
- Telecom time synchronous clock (T-TSC) specification. The T-TSC is a device consisting of a timeReceiver clock as specified in [IEEE 1588-2008] with additional performance characteristics. [ITU-T G.8273.2] specifies T-TSC.
- Partial timing support T-BCs (T-BC-partial support), T-BC-assisted) and T-TSCs (T-TSC-partial support, T-TSC-assisted). The details of these clocks are specified in [ITU-T G.8273.4].

Annex A

Testing and measurement of time or phase clocks

(This annex forms an integral part of this Recommendation.)

A.1 Introduction

Measurement of time or phase behaviour of clocks is substantively different from measurement of their frequency behaviour. The basis for the measurement in both cases is time error but for frequency-based measurements the time interval error information is extracted and the typical metrics used are maximum time interval error (MTIE) and time deviation (TDEV). These metrics are appropriate since the absolute value of time error is moot for frequency. In fact, MTIE can be viewed as a stability measure based on peak-to-peak time error (over an observation interval) and the average value is of little consequence. In the case of TDEV, the goal is to characterize the noise processes and consequently it is advantageous to suppress the mean time error as well as the (average) frequency offset.

Frequency metrics, such as MTIE, TDEV and fractional frequency offset can be applied to time or phase clocks and such measurements may have value when assessing their stability; such metrics are not sufficient to characterize their time error. One metric that is distinct from those of frequency is the constant time error (cTE). The use of constant, dynamic and frequency metrics to characterize stability of a time or phase clock is for further study.

The concentration in this Recommendation is on packet-based methods for transferring time or phase. For specificity, methods based on the PTP [IEEE 1588] are considered.

A.1.1 TimeTransmitter port time-stamp error

There are four time stamps that are relevant in the PTP. These are as follows.

- Associated with the *SYNC* message:
 - 1) T_1 : time of departure from timeTransmitter port;
 - 2) T_2 : time of arrival at timeReceiver port.
- Associated with *DELAY_REQUEST* message:
 - 3) T_3 : time of departure from timeReceiver port;
 - 4) T_4 : time of arrival at timeTransmitter port.

Of these time stamps, T_2 and T_3 are struck at the timeReceiver port and are not visible externally (T_3 may be visible from some devices). Time stamps T_1 and T_4 are visible externally. T_1 is available in the *SYNC* (or *FOLLOW_UP*) message and T_4 is available in the *DELAY_RESPONSE* message. The accuracy of these time stamps is quantified by the difference between the time stamp as struck and the system under test (SUT) time clock at the actual time of departure or time of arrival of the *SYNC* and *DELAY_REQUEST* packets, respectively. The measurement device can utilize as its time reference for measurement the same reference provided to the GM as described in Annex B.

It should be noted that T_1 and T_4 are not single time-stamp values. T_1 is the presentation by the timeTransmitter port of its best estimate of the time of departure of the *SYNC* message. This shall be presented in the *originTimestamp* plus *correctionField* of the *SYNC* message (in one step clocks) or in the *preciseOriginTimestamp* plus *correctionField* of the *FOLLOW_UP* message (in two-step clocks). T_4 is the presentation by the timeTransmitter port of its best estimate of the time of arrival of the *DELAY_REQUEST* message. This shall be presented in the *receiveTimestamp* of the *DELAY_RESPONSE* message plus the difference between the *correctionField* of the *DELAY_REQUEST* message and the *correctionField* of the *DELAY_RESPONSE* message.

Since there are multiple time stamps used to represent T_1 and T_4 values, additional error budgeting beyond simple single time-stamp granularity may be required.

A measurement device placed at a calibrated distance from the timeTransmitter port can estimate the time of departure of a *SYNC* message from the timeTransmitter port by time-stamping the passage of the *SYNC* message. Denote this measurement by $T_{1\text{REF}}$. By parsing the *SYNC* message (or *FOLLOW_UP*), the time of departure of the *SYNC* message as struck by the timeTransmitter port, T_1 , is established. The accuracy of the time stamp is quantified by the time error (sequence) TE_1 given by:

$$TE_1 = T_1 - T_{1\text{REF}} \quad (\text{A.1.1})$$

The observed time error is compared against the specified limit Y_1 . The pass criterion is:

$$|TE_1| \leq Y_1 \quad (\text{A.1.2})$$

The limit Y_1 is application dependent and is specified in the relevant clock specification. As recommended in [IEEE 1588], Y_1 is commensurate with the required accuracy of the application. The further allocation to cTE and dTE (time noise) and systematic errors is for further study.

A measurement device placed at a calibrated distance from the timeTransmitter port can estimate the time of arrival of a *DELAY_REQUEST* message from the timeTransmitter port by time-stamping the passage of the *DELAY_REQUEST* message. Denote this measurement by $T_{4\text{REF}}$. By parsing the *DELAY_RESPONSE* message, the time of arrival of the *DELAY_REQUEST* message as struck by the timeTransmitter port, T_4 , is established. The accuracy of the time stamp is quantified by the time error (sequence) TE_4 given by:

$$TE_4 = T_4 - T_{4\text{REF}} \quad (\text{A.1.3})$$

The observed time error is compared against the specified limit Y_4 . The pass criterion is:

$$|TE_4| \leq Y_4 \quad (\text{A.1.4})$$

The limit Y_4 is application dependent and is specified in the relevant clock specification. As recommended in [IEEE 1588], Y_4 is commensurate with the required accuracy of the application. The further allocation to cTE and dTE (time noise) and systematic errors is for further study.

Measuring the time-error TE_1 is achieved by time-stamping the passage of a *SYNC* message at a calibrated distance from the timeTransmitter port. Similarly, TE_4 is measured by time-stamping the passage of a *DELAY_REQUEST* message at a calibrated distance from the timeTransmitter port. If the test device is a PTP probe, the relevant time stamps generated in the probe would be the time of arrival of a *SYNC* message from the timeTransmitter and the time of departure of a *DELAY_REQUEST* message to the timeTransmitter. This is depicted in Figure A.1-1.

Guidelines for the measurement include the following.

- a) The timeTransmitter device and the test device are provided with a common time or phase reference and it is assumed that any synchronization error associated with locking to this reference is negligible. Such synchronization errors should be maintained at a level to facilitate the verification of the time error limit. Any systematic errors associated with synchronization and 1 pulse/s (1 pulse per second; 1 PPS) interface should be accounted for.
- b) The test device must be calibrated and the time-stamp accuracy and granularity of time stamps struck by the test device should be maintained at a level to facilitate the verification of the time error limit.
- c) Annex B includes several testing configurations identifying the manner in which an external time or phase reference is provided to the different pieces of equipment involved.

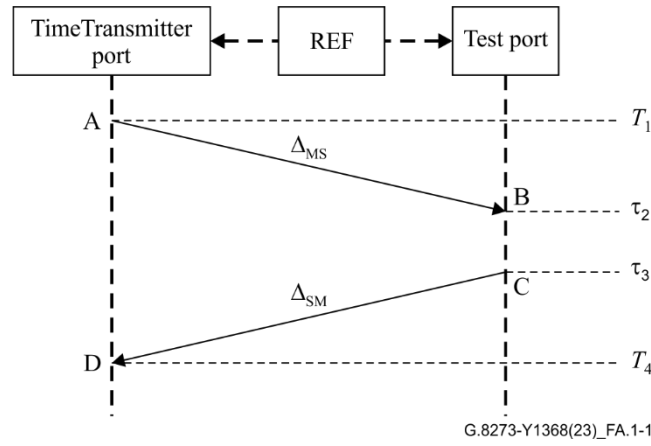


Figure A.1-1 – Depicting the situation where the system under test is connected to a test device and PTP messages are exchanged

At time A the timeTransmitter sends a *SYNC* message with time stamp T_1 . The packet arrives at the test device at B and the time of arrival noted as τ_2 . The estimate of the forward transmission delay, Δ_F , is given by:

$$\Delta_F = \tau_2 - T_1 \quad (\text{A.1.5})$$

The test device sends a *DELAY_REQUEST* packet at C and the time of departure noted as τ_3 . The time of arrival at the timeTransmitter, at D, is noted as T_4 and this value is returned in the *DELAY_RESPONSE* message. The estimate of reverse transmission delay, Δ_R , is given by:

$$\Delta_R = T_4 - \tau_3 \quad (\text{A.1.6})$$

In order to verify the accuracy of the time stamps T_1 and T_4 , the transmission delays in the interconnecting medium (e.g., fibre) have to be controlled. Specifically, the cable length is calibrated and the delays Δ_{MS} and Δ_{SM} are known to have a reasonable level of accuracy. Equations A.1.5 and A.1.6 provide estimates of transmission delays based on the time stamps struck by the timeTransmitter and therefore the time-stamp accuracy is confirmed if:

$$\begin{aligned} |\Delta_F - \Delta_{MS}| &< Y_1 \\ |\Delta_R - \Delta_{SM}| &< Y_4 \end{aligned} \quad (\text{A.1.7})$$

where Y_1 and Y_4 are the prescribed limits for time-stamp accuracy. The further allocation to cTE and dTE (time noise) is for further study.

A.1.2 TimeTransmitter port time-transfer error

Considering a device downstream from the timeTransmitter port, the time transfer time error is dependent indirectly on the accuracy of time stamps T_1 and T_4 and directly on a combination thereof. The time transfer time error can be measured by providing a common time reference to the timeTransmitter port and monitoring device (test port) as shown in Figure A.1-1. Assuming that the cable delay is symmetric, i.e., $\Delta_{MS} = \Delta_{SM} = \Delta$, the time error signal, $T_{err}(t)$ can be expressed as:

$$T_{err}(t) = \frac{(T_4(t) + T_1(t)) - (\tau_3(t) + \tau_2(t))}{2} \quad (\text{A.1.8})$$

where the terms $T_4(t)$, $T_1(t)$, $\tau_3(t)$ and $\tau_2(t)$ represent the implicit signals corresponding to the time-stamping processes. Calculation of wander metrics is conventionally performed on samples of $T_{err}(t)$, namely $\{T_{err}(k\tau_0)\}$, where the samples are taken on a uniform time grid with sampling interval $\tau_0 < (1/30)$.

However, the packet rates in the two directions can be different and the relative phasing non-deterministic. Consequently, denoting the (symmetric) cable delay by Δ , the time error components TE_1 and TE_4 are computed as:

$$\begin{aligned} TE_1(n) &= T_1(n) + \Delta - \tau_2(n) \\ TE_4(m) &= T_4(m) - \Delta - \tau_3(m) \end{aligned} \quad (\text{A.1.9})$$

The indices n and m indicate the packet sequence number and serve as a sampling index for the different time signals. The time transfer error is determined by a combination of the two discrete-time sequences $\{TE_1(n)\}$ and $\{TE_4(m)\}$. Depending on the configured parameters of the IEEE-1588-2008 flow, the two sequences could have different sampling rates and non-overlapping grids of sampling points. The methodology for combining the sequences is for further study.

The time error can be considered in two parts, one is the cTE and the other is the dTE or time noise. The time noise generation requirement is for further study. The cTE component of the time error is derived by combining the cTE of each sequence computed separately.

For a timeTransmitter port, the cTE transfer requirement is satisfied if:

$$\frac{|\langle TE_1(n) \rangle + \langle TE_4(m) \rangle|}{2} < X_{\text{CONSTANT}} \quad (\text{A.1.10})$$

where the notation $\langle \rangle$ is used for the cTE estimation and X_{CONSTANT} is the prescribed limit for cTE generation for the timeTransmitter port provided in the appropriate Recommendation of the ITU-T G.8273.x series.

The implication of satisfying Equation A.1.10 is that the timeTransmitter port is capable of delivering time to a downstream device that is within X_{CONSTANT} of the underlying time clock of the timeTransmitter port, in terms of cTE.

A.2 Grandmaster clocks

The time error generation requirement for a GM clock is X_{GM} ns. That is,

$$|T_{\text{GM}}(t) - T_{\text{REF}}(t)| < X_{\text{GM}} \quad (\text{A.2.1})$$

where t represents the mathematical progression of time as an independent variable, T_{REF} is the time value of the reference provided to the GM and T_{GM} is the time value of the GM. The value for X_{GM} is specified in [ITU-T G.8272 and [ITU-T G.8272.1].

See Figure A.2-1.

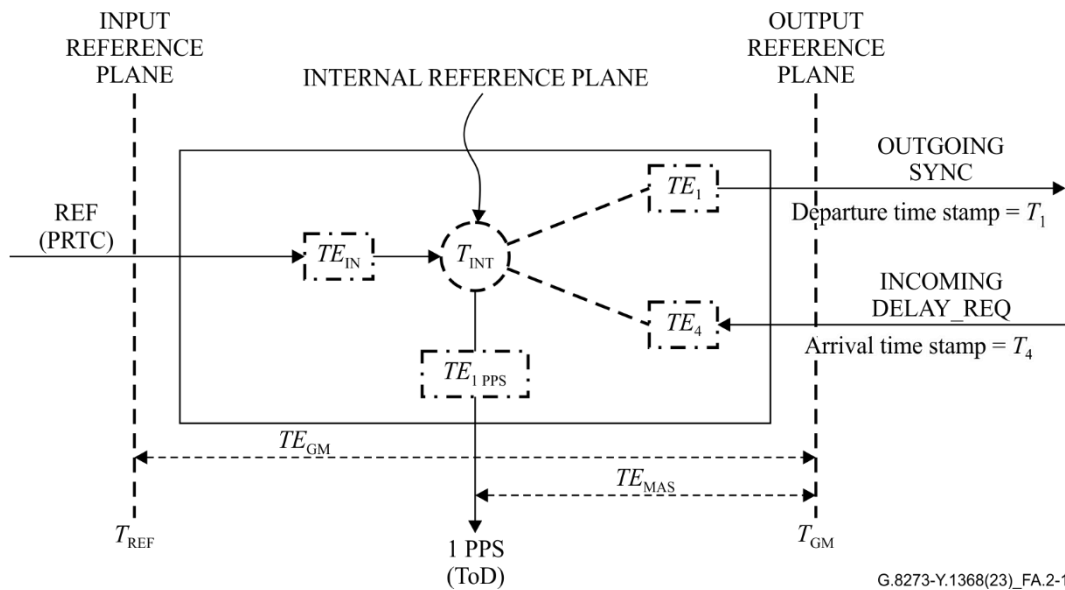


Figure A.2-1 – Noise generation model for a grandmaster clock

A GM clock receives its reference from a primary reference time clock (PRTC) or, in the event that the T-GM and PRTC are combined, the reference may come from other sources such as a global