
ITU-T profiles for IEEE 1588

Silvana Rodrigues, Director Systems Design

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Introduction

With the transition from time-division multiplexing (TDM) to packet switched networks, the need to transport time/synchronization over a packet network became a necessity. IEEE 1588 (IEEE Std 1588™-2008 [1]), also known as Precision Time Protocol (PTP), is becoming the main protocol to transport precision time/phase/frequency over packet networks. IEEE 1588 [1] defines a protocol to distribute synchronization over packets networks; it is a very precise protocol with many features and options that can be used to address a wide range of applications. Not all the options and features are needed for a particular application and therefore IEEE 1588 developed the concept of profile. Clause 19.2.3 of IEEE 1588 [1] defines a profile as follows:

“The purpose of a PTP profile is to allow organizations to specify specific selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-work and achieve a performance that meets the requirements of a particular application. A PTP profile is a set of required options, prohibited options, and the ranges and defaults of configurable attributes.”

Several standards organizations have been working on profiles for IEEE 1588. The profiles are developed to fulfill specific requirements dependent on the application. The International Telecommunication Union (ITU) developed and is still developing profiles for use in telecommunications. Wireless application is the main driver for the profiles being developed at ITU. ITU also develops a series of recommendations that are used along with the profile to meet synchronization requirements needed by the telecom application.

There have been several publications on the use of IEEE 1588 for telecom networks. References [18] and [19] are two publications in which IDT has been involved.

Frequency Profile

ITU-T G.8265.1 (ITU Telecommunications Standardization Sector) defines the “Precision time protocol telecom profile for frequency synchronization” [2]. It defines the options and attributes from IEEE 1588 to be used to deliver frequency synchronization to the end application. The concept of this profile is shown in Figure 1.

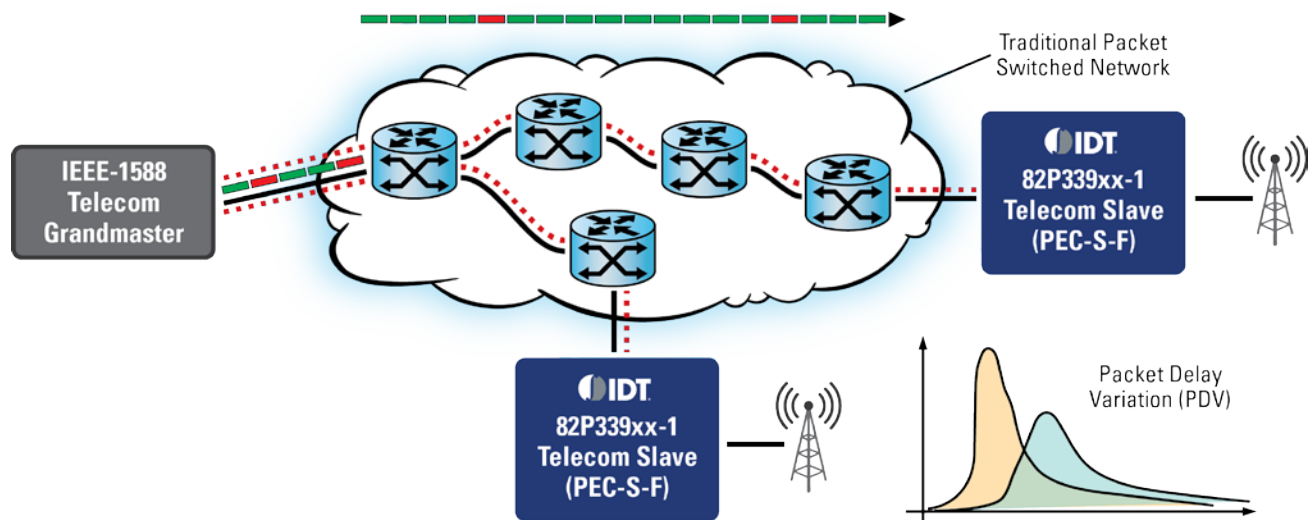


Figure 1: ITU-T G.8265.1 Frequency Profile IEEE 1588 without support from Network

This profile does not use any assistance from the network between the telecom grandmaster and the telecom slave, such as boundary clocks or transparent clocks as defined in IEEE 1588, and therefore the performance is dependent of the network. Due to the shared resources nature of packet networks, the packets will experience variable delays. Depending on the network condition each packet will experience its own propagation delay from the telecom grandmaster to the telecom slave and vice-versa. The difference between propagation delays of the same type of packets is called Packet Delay Variation (PDV) and greatly affects the quality of the recovered clock.

IEEE 1588 does not standardize the clock recovery algorithm, so proprietary solutions are needed, and appropriated filtering algorithm is a key part of the solution. Clause A.2 of IEEE Standard 1588™-2008 [1] states “Bridges not implementing PTP may introduce considerable timing jitter and path asymmetry. Although such bridges may be included in a system implementing PTP, these bridges should not be used unless timing errors introduced by their jitter and path asymmetry are tolerable for the application, or can be reduced by an appropriate filtering algorithm.” IDT has a state-of-art packet clock recovery algorithm that implements an IDT-patented filtering algorithm that was developed to work with networks with high level of PDV. The IDT IEEE 1588 software runs on an external processor and controls the IDT Synchronization Management Unit (SMU) hardware (82P339xx-1 family of devices) through an I²C or SPI interface. IEEE 1588 performance reports are available for customers under NDA (contact IDT by emailing clocks@idt.com).

As this profile was developed for frequency synchronization, one-way time transfer mode can be used for the clock recovery. However the profile allows for both one-way and two-way time transfer modes. IDT prefers the two-way method in order to take advantage of the direction with the lowest PDV. However the one-way method is also supported.

Unicast messages are used for this profile. The PTP mappings defined in IEEE 1588 Annex D and E, IPv4 and IPv6 respectively, are used. Also, the unicast message is used to establish a PTP domain. The domain numbers can be set between 4 and 23 with the default being 4.

The messages types and message rates used in this profile are:

- Sync /Follow-up – min rate: 1 packet every 16 seconds, max rate: 128 packets per second
- Delay_Request/Delay_Response – min rate: 1 packet every 16 seconds, max rate: 128 packets per second
- Announce – min rate: 1 packet every 16 seconds, max rate: 8 packets per second, default: 1 packet every 2 seconds
- Signaling messages – no rate is specified

IEEE 1588 defines a default Best Mast Clock Algorithm (BMCA), but it also allows a profile to define an alternate BMCA (ABMCA) as long as the behavior of the PTP protocol is preserved.

The alternate BMCA in G.8265.1 is static; each master is isolated by a separated PTP domain that is done through the unicast communication. The ABMCA has the following characteristics:

- Grandmasters do not exchange Announce messages.
- Masters are always active
- Slaves are always slave-only clocks

For the telecom networks it is very important to have protection schemes by using redundant hardware and redundant grandmaster clocks. ITU-T G.8265.1 defines the concept of a “telecom slave” clock. The “telecom slave” consists of one or multiple PTP slave-only ordinary clock instances; this allows a slave node to listen to several grandmasters and any of them can be selected as grandmaster. The grandmaster selection process

is based on the synchronization status message (SSM) Quality Level (QL) per ITU-T Recommendation G.781 [3]. The grandmaster selection also takes into consideration the Packet Timing Signal Fail (PTSF) and the grandmaster priority.

The Clock Class attribute in the Announce messages in PTP is used to carry the SSM QL value. The master with the highest QL that is not experiencing a PTSF failure condition will be selected as the grandmaster. In case of masters with similar QL values that are not experiencing a PTSF failure condition, the master with the highest priority is selected. The priority is set for each master, and it is locally maintained in the telecom slaves.

There are different PTSF signals defined in G.8265.1, they are:

- PTSF-lossSync : signals the lack of sync messages being received by the slave from the master
- PTSF-lossAnnounce: signals the lack of Announce messages being received by the slave from the master
- PTSF-unusable: signals the excessive PDV noise at the input of the slave (violates the slave input tolerance defined in ITU-T Recommendations G.8261.1 [4] and G.8263 [5]). The use of PTSF-unusable is implementation specific and it is for further study.

ITU-T developed a series of recommendations for frequency synchronization performance that are important part of the whole solution, they are:

- ITU-T Recommendation G.8261, Timing and synchronization aspects in packet networks [6]
 - G.8261 specifies the frequency synchronization requirements that are needed in packet switched networks. Even though Appendices in ITU Recommendations are not binding requirements, Appendix VI of G.8261 is widely used in the telecom industry to test slave clocks.
- Recommendation ITU-T G.8261.1, Packet Delay Variation Network Limits applicable to Packet Based Methods (Frequency Synchronization).
 - G.8261.1 specifies the hypothetical reference model (HRM) and the PDV network limit expected by the packet slave clock defined in ITU-T G.8263.
- Recommendation ITU-T G.8263, Timing Characteristics of Packet based Equipment Clocks
 - G.8263 specifies requirements for the packet-based Equipment Clock – Slave – Frequency (PEC-S-F) used in G.8265.1 profile and G.8265 architecture recommendations. It specifies the frequency accuracy, the noise generation, packet delay variation noise tolerance, the holdover performance and the interfaces.
- ITU-T Recommendation G.8265, Architecture and requirements for packet based frequency delivery [7]
 - G.8265 describes frequency synchronization architecture for packet networks.
- ITU-T Recommendation G.8260, Definitions and terminology for synchronization in packet networks [8]
 - G.8260 describes definitions and terminology for synchronization in packet networks

Phase/time profile with full timing support from the network

ITU-T Recommendation G.8275.1 defines the “Precision time protocol telecom profile for phase/time synchronization with full timing support from the network” [9]. It defines the options and attributes from IEEE 1588 to be used to deliver phase/time synchronization to the end application. The concept of this profile is shown in Figure 2.

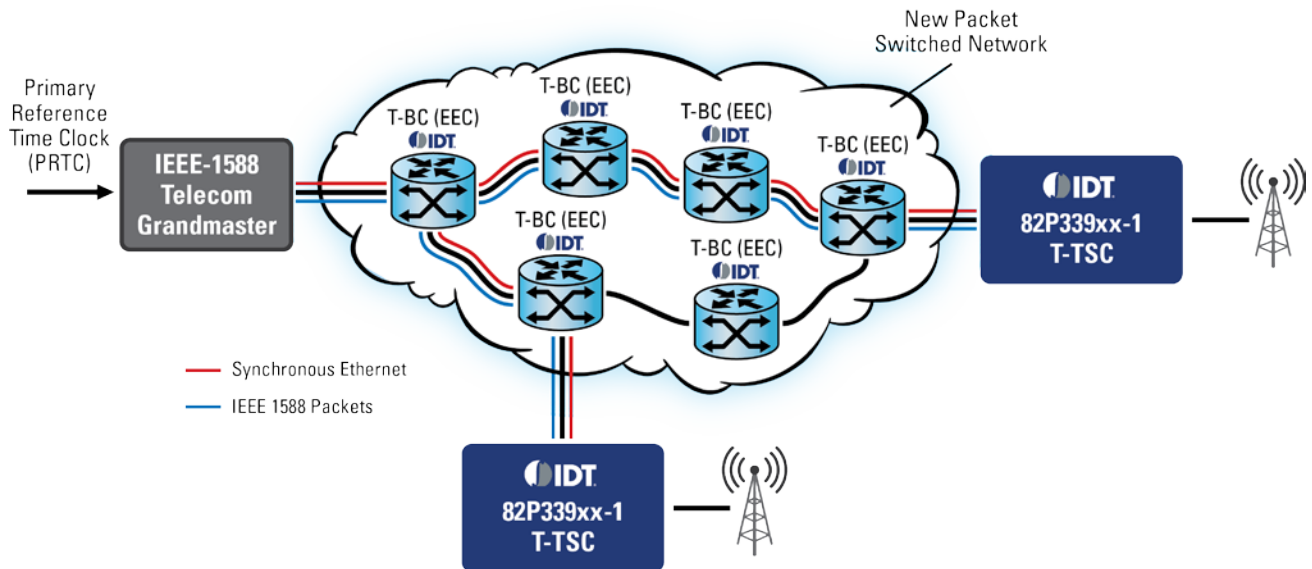


Figure 2: G.8275.1 ITU-T Time/Phase Profile IEEE 1588 with Full Support from Network

This profile uses Telecom Boundary Clocks (T-BC) and therefore the performance is not affected by the PDV of the network. Also, the use of Synchronous Ethernet is mandatory with this profile. The use of transparent clocks for this profile is still under development at ITU-T.

This profile was developed for phase/time synchronization and therefore it needs to measure the propagation delay, in order to do that the use of two-way time transfer mode is mandatory.

Multicast messages are used for this profile with the PTP mappings defined in IEEE 1588 Annex F. Both the non-forwardable and forwardable multicast addresses are permitted (01-80-C2-00-00-0E and 01-1B-19-00-00-00 respectively). The multicast address is set by configuration on a per-PTP port basis, but both non-forwardable and forwardable multicast addresses must be accepted by the PTP port.

The PTP domain numbers can be set between 24 and 43 with the default being 24.

The message types and message rates used in this profile are:

- Sync /Follow-up: fixed nominal rate of 16 packets per second
- Delay_Request/Delay_Response:
- Announce: fixed nominal rate of 8 packets per second

G.8275.1 uses an alternate BMCA that is based on the IEEE 1588 default BMCA. It has provisions to allow a manual network planning. The alternate BMCA allows:

- Multiple grandmasters to be active simultaneously
- Per-port Boolean attribute notSlave. If notSlave is set to TRUE, then the port is never placed in the SLAVE state. If notSlave is set to FALSE, then the port can be placed in the SLAVE state
- Per-port attribute localPriority to be used as a tie-breaker in the dataset comparison algorithm. By using different values than their default value allows building manually the synchronization network topology
- The clock attribute priority1 is static
- The clock attribute priority2 is configurable
- The clock attributes clockAccuracy and offsetScaledLogVariance must be set to specific values defined in G.8275.1
- G.8275.1 also specifies the clockClass values to be used.

The profile defined in G.8275.1 is used for protocol interoperability and it does not address performance. However performance is an essential part of the whole solution, and therefore ITU-T developed a series of recommendations for phase/time synchronization performance that are important part of the whole solution, they are:

- ITU T Recommendation G.8271, Time and phase synchronization aspects of packet networks [12]
 - G.8271 specifies the time and phase synchronization aspects that are needed in packet switched networks.
- ITU T Recommendation G.8271.1, Network limits for time synchronization in Packet networks [10]
 - G.8271.1 specifies the time and phase error requirements for packet switched networks. It addresses the requirements of phase and time distributed over network with full timing support (T-BCs in every node)
- ITU T Recommendation G.8272, Timing characteristics of Primary reference time clock [13]
 - G.8272 specifies the timing characteristics of timing characteristics of primary reference time clock (PRTC); it also covers the requirements of equipment that integrates PRTC and telecom grandmaster (T-GM). It defines time error, wander and jitter in locked mode. It also defines the interfaces that may be used in this type of equipment.
- ITU-T Recommendation G.8273, Framework of phase and time clocks [14]
 - G.8273 serves as a framework for the time and phase clocks. It defines testing and measurement methods and techniques for the different types of clocks used for time and phase.
- ITU-T Recommendation G.8273.2, Timing characteristics of telecom boundary clocks and telecom time slave clocks [11]
 - G.8273.2 specifies the requirements for telecom boundary clocks (T-BCs) and telecom time slave clocks (T-TSCs). It specifies the T-BC and T-TSC performance requirements for full timing support from the network with synchronous Ethernet assistance.
- ITU-T Recommendation G.8275, Architecture and requirements for packet-based time and phase delivery [15]
 - G.8275 describes time and phase synchronization architecture for packet networks.

Even though all the Recommendations listed above are important, this white paper will call attention to a few requirements listed in G.8271, G.8271.1 and G.8273.2 as these requirements are very much related to the Phase/Time Profile.

ITU-T Recommendation G.8271 [12] defines several classes of performance, below Table 1 of G.8271 Amendment 1 is copied for reference; it presents several different applications time error requirements.

G.8271 Amd1/Table 1 – Time and Phase Requirement Classes

Level of accuracy	Time error requirements (Note 1)	Typical applications (for information)
1	500 ms	Billing, alarms
2	100 μ s	IP Delay monitoring
3	5 μ s	LTE TDD (large cell)
4	1.5 μ s	UTRA-TDD, LTE-TDD (small cell) Wimax-TDD (some configurations)
5	1 μ s	Wimax-TDD (some configurations)
6	x ns (Note 3)	Location based services and some LTE-A features (Note 2)

NOTE 1 – The requirement is expressed in terms of error with respect to a common reference.

NOTE 2 – The performance requirements of the LTE-A features are under study. For information purposes only, values between 500 ns and 1.5 μ s have been mentioned for some LTE-A features. Depending on the final specifications developed by 3GPP, LTE-A applications may be handled in a different level of accuracy.

NOTE 3 – The value for x is for further study.

The time error budgeting used in the architecture defined in ITU-T Recommendation G.8271.1 [10] addresses class 4 of G.8271/Table 1, so the time/phase error requirements from the Primary Reference Time Clock (PRTC) to the end application is 1.5 μ s (see Figure 3). G.8271.1 defines several HRMs used for the phase/time profile; they use either a shorter chain of T-BCs or a longer chain of T-BCs as depicted in Figure 3.

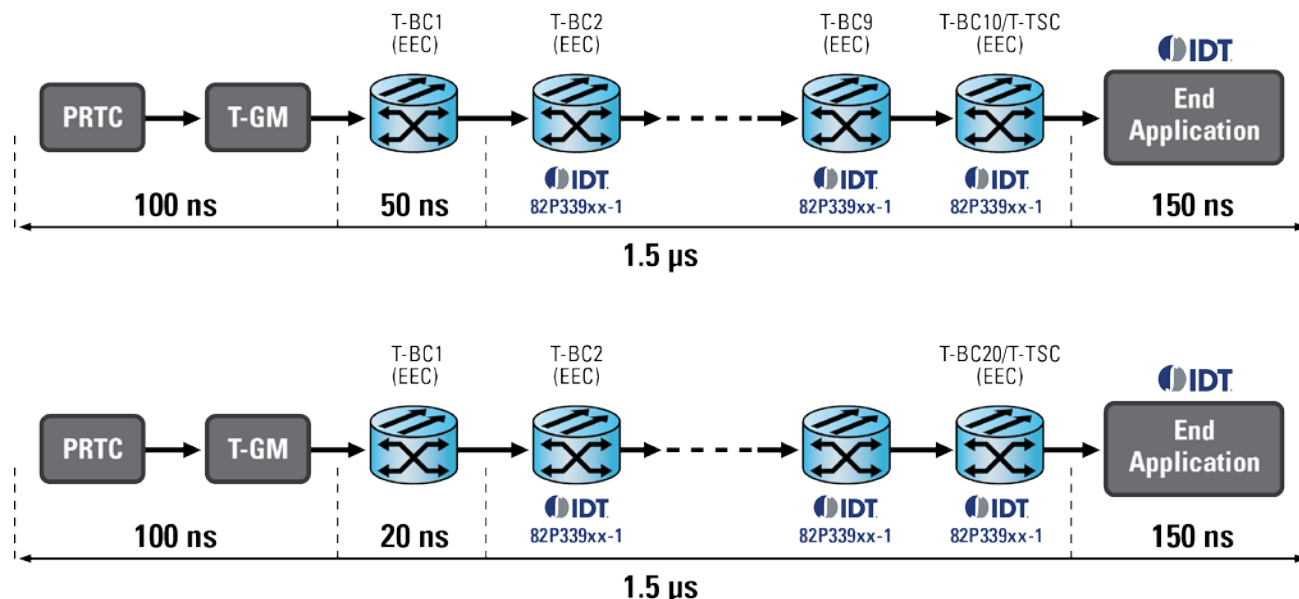


Figure 3: ITU-T G.8275.1 Time/Phase Profile Architecture

ITU-T Recommendation G.8273.2 [11] defines two types of Telecom Boundary Clocks (T-BC) and Telecom Slave clocks (T-TSC) to be used in the telecom network. T-BC/T-TSC class A that is specified to have a maximum constant time error of 50ns to be used in shorter chains (up to 10 nodes), and T-BC/T-TSC class B that is specified to have a maximum constant time error of 20ns to be used in longer chains (up to 20 nodes).

It also makes reference to synchronous Ethernet (ITU-T Recommendation G.8262, see reference [16]) as the current T-BC and T-TSC defined in G.8273.2 was developed for time transport via PTP and frequency transport via synchronous Ethernet (SyncE). Appendix III of G.8273.2 describes some simple diagrams of T-BC to show the signal flow for the time/phase path and the frequency path. The architecture developed by IDT for the Synchronization Management Unit (SMU) hardware (IDT's 82P339xx-1 family of devices) is perfectly designed to fulfill G.8273.2 requirements. The 82P339xx-1 family has a mode (called "combo mode") that allows independent path for the IEEE 1588 and SyncE. Another key advantage of this family of devices is the T-BC hardware filtering allowing systems to guarantee a loop bandwidth between 0.05Hz to 0.1Hz as defined in G.8273.2. The loop bandwidth it is set in hardware and therefore it is completely independent of the IEEE 1588 software. IDT's 82P339xx-1 family also has several phase alignment features to easy system implementations to meet the tight phase requirements in G.8273.2. More detailed information is available from IDT (contact IDT by emailing clocks@idt.com).

Phase/time profile with partial timing support from the network

ITU-T G.8275.2 defines the “Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network” (see Reference [17]). It defines the options and attributes from IEEE 1588 to be used to deliver phase/time synchronization to the end application. The concept of this profile is shown in Figure 4.

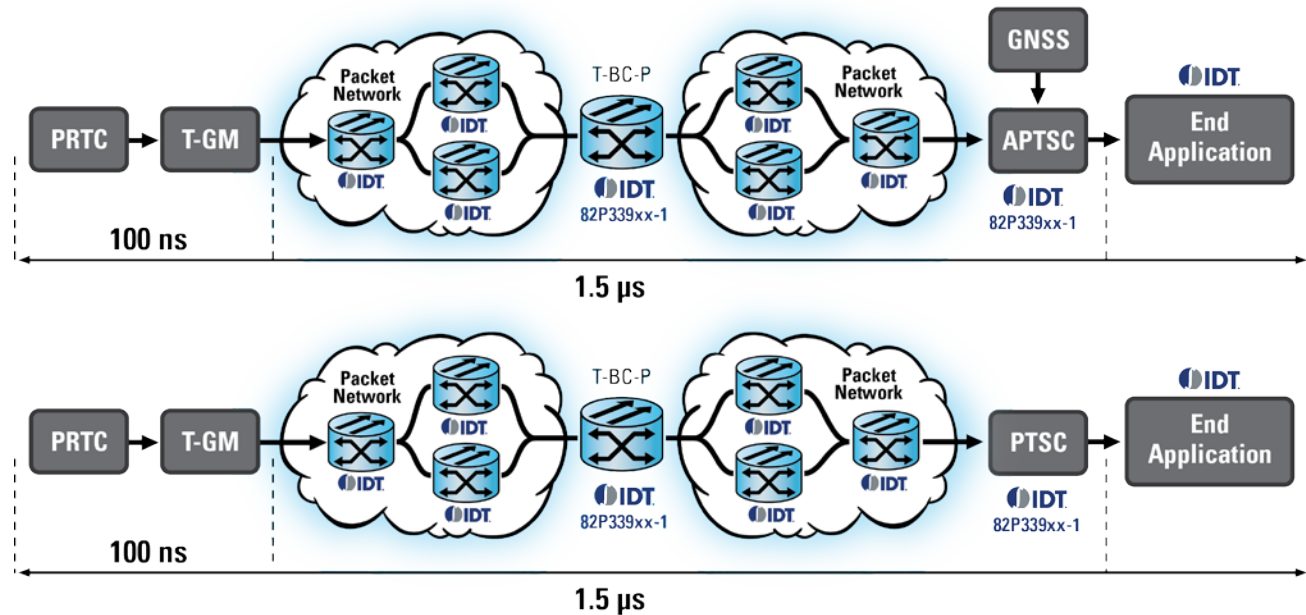


Figure 4: ITU-T G.8275.1 Time/Phase Profile IEEE 1588 with Partial Support from Network

There are 2 main deployment cases for this profile. The first one is for the Assisted Partial Time Support (APTS). In this case there will be a Global Navigation Satellite System (GNSS) co-located with the APTS clock (APTSC) and IEEE 1588 will be used as a back-up to GNSS. The second case, the PTSC will need to recover time/phase using IEEE 1588. This profile is still under development at ITU.

References

[1] IEEE Std 1588™-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, IEEE Instrumentation and Measurement Society, July 2008 (<http://standards.ieee.org/findstds/standard/1588-2008.html>)

The following ITU-T Recommendations can be downloaded from the ITU web site at <http://www.itu.int/rec/T-REC-G/e>.

[2] Recommendation ITU-T G.8265.1 (2014), Precision time protocol telecom profile for frequency synchronization

[3] Recommendation ITU-T G.781 (2008), Synchronization layer functions.

[4] ITU-T Recommendation G.8261.1, Packet Delay Variation Network Limits applicable to Packet Based Methods (Frequency Synchronization).

[5] ITU-T Recommendation G.8263, Timing Characteristics of Packet based Equipment Clocks

- [6] ITU T Recommendation G.8261, Timing and synchronization aspects in packet networks.
- [7] ITU-T Recommendation G.8265, Architecture and requirements for packet based frequency delivery
- [8] ITU-T Recommendation G.8260, Definitions and terminology for synchronization in packet networks
- [9] Recommendation ITU-T G.8275.1/Y.1369.1 (2014), Precision time protocol telecom profile for phase/time synchronization with full timing support from the network.
- [10] Recommendation ITU-T G.8271.1/Y.1366.1 (2014), Network limits for time synchronization in packet networks.
- [11] Recommendation ITU-T G.8273.2/Y.1368.2 (2014), Timing characteristics of telecom boundary clocks and telecom time slave clocks.
- [12] Recommendation ITU-T G.8271/Y.1366 (2012), Time and phase synchronization aspects of packet networks.
- [13] Recommendation ITU-T G.8272/Y.1367 (2012), Timing characteristics of primary reference time clocks.
- [14] Recommendation ITU-T G.8273/Y.1368 (2013), Framework of phase and time clocks.
- [15] Recommendation ITU-T G.8275/Y.1369 (2013), Architecture and requirements for packet-based time and phase distribution
- [16] Recommendation ITU-T G.8262/Y.1362 (2010), Timing characteristics of a synchronous Ethernet equipment slave clock
- [17] Draft Recommendation ITU-T G.8275.2/Y.1369.2 (draft), Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network. (This Recommendation is not available from the ITU-T web site as it is still work in progress; however it is available for ITU-T members).
- [18] J.-L. Ferrant, M. Gilson, S. Jobert, M. Mayer, M. Ouellette, L. Montini, S Rodrigues, S. Ruffini, "Development of the First IEEE 1588 Telecom Profile to Address Mobile Backhaul Needs", IEEE Communications Magazine, October 2010, pages 118-126.
- [19] Synchronous Ethernet and IEEE 1588 in Telecoms / Next Generation Synchronization Networks, J.-L. Ferrant, M. Gilson, S. Jobert, M. Mayer, M. Ouellette, L. Montini, S Rodrigues, S. Ruffini, ISBN: 9781848214439. Published in May 2013 by ISTE and Wiley