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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

Time and phase synchronization aspects of telecommunication networks

Recommendation ITU-T G.8271/Y.1366

ITU-T G-SERIES RECOMMENDATIONS
TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
Ethernet over Transport aspects	G.8000–G.8099
MPLS over Transport aspects	G.8100–G.8199
Synchronization, quality and availability targets	G.8200–G.8299
Service Management	G.8600–G.8699
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.8271/Y.1366

Time and phase synchronization aspects of telecommunication networks

Summary

Recommendation ITU-T G.8271/Y.1366 defines time and phase synchronization aspects in packet networks. It specifies the suitable methods to distribute the reference timing signals that can be used to recover the phase synchronization and/or time synchronization according to the required quality.

The requirements for the synchronization characteristics that are specified in this Recommendation must be adhered to in order to ensure interoperability of equipment produced by different manufacturers and a satisfactory network performance.

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at <http://www.itu.int/ITU-T/ipr/>.

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Table of Contents

	Page
1 Scope	1
2 References.....	1
3 Definitions	2
4 Abbreviations and acronyms	2
5 Conventions	4
6 The need for time and phase synchronization	4
7 Time and phase synchronization methods.....	6
7.1 Distributed PRTC	7
7.2 Packet based methods with timing support of intermediate nodes.....	8
8 Network reference model	9
8.1 Access section of HRM with PTP/native access IWF.....	11
9 Time and phase synchronization interfaces.....	12
Annex A – One pulse-per-second (1PPS) time and phase synchronization interface specification.....	13
A.1 1PPS ITU-T V.11 interface	13
A.2 1PPS 50 Ω phase synchronization measurement interface	20
Appendix I – Time and phase noise sources in time distribution chains.....	21
I.1 Noise introduced by a primary reference time clock (PRTC).....	21
I.2 Noise introduced by a packet master clock function.....	21
I.3 Noise introduced by a packet slave clock function	21
I.4 Noise introduced by a telecom transparent clock.....	22
I.5 Noise introduced by a link.....	22
I.6 Derivation of delay asymmetry	22
I.7 Characteristics of the noise sources.....	24
I.8 Time error accumulation in a chain of clocks	26
Appendix II – Time and phase end application synchronization requirements.....	27
Appendix III – Asymmetry compensation for use of different wavelengths.....	31
Appendix IV – Link and network asymmetry compensation	32
Appendix V – Delay asymmetry resulting from interface rate change in PTP-unaware network elements.....	35
Appendix VI – Time synchronization aspects in TDD based mobile communication systems.....	38
VI.1 An overview of radio-interference in TDD systems	38
VI.2 Signal frame format of TDD systems.....	39
VI.3 Base station to base station interference.....	40
VI.4 User equipment to user equipment interference.....	41

	Page
Appendix VII – Time scales	42
VII.1 Time scales	42
VII.2 Relationship between time scales	43
Bibliography.....	44

Recommendation ITU-T G.8271/Y.1366

Time and phase synchronization aspects of telecommunication networks

1 Scope

This Recommendation defines time and phase synchronization aspects in telecommunication networks. It specifies the suitable methods to distribute the reference timing signals that can be used to recover the phase synchronization and/or time synchronization according to the required quality. It also specifies the relevant time and phase synchronization interfaces and related performance.

The telecommunication networks that are in the scope of this Recommendation are currently limited to the following scenarios:

- 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 [RFC 2460]);
- optical transport network (OTN) ([ITU-T G.709]).

The physical layers that are relevant to this Recommendation are the Ethernet media types, as defined in [IEEE 802.3], and, for OTN, the optical OCh layer with optical transport network (OTU) frame as defined in [ITU-T G.709].

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.703] | Recommendation ITU-T G.703 (2016), <i>Physical/electrical characteristics of hierarchical digital interfaces.</i> |
| [ITU-T G.709] | Recommendation ITU-T G.709/Y.1331 (2016), <i>Interfaces for the optical transport network.</i> |
| [ITU-T G.810] | Recommendation ITU-T G.810 (1996), <i>Definitions and terminology for synchronization networks.</i> |
| [ITU-T G.8110] | Recommendation ITU-T G.8110/Y.1370 (2005), <i>MPLS layer network architecture.</i> |
| [ITU-T G.8260] | Recommendation ITU-T G.8260 (2020), <i>Definitions and terminology for synchronization in packet networks.</i> |
| [ITU-T G.8261] | Recommendation ITU-T G.8261/Y.1361 (2019), <i>Timing and synchronization aspects in packet networks.</i> |
| [ITU-T G.8272] | Recommendation ITU-T G.8272/Y.1367 (2018), <i>Timing characteristics of primary reference time clocks.</i> |
| [ITU-T V.11] | Recommendation ITU-T V.11/X.27 (1996), <i>Electrical characteristics for balanced double-current interchange circuits operating at data signalling rates up to 10 Mbit/s.</i> |

- [IEEE 802.1Q] IEEE 802.1Q-2018, *IEEE Standard for Local and metropolitan area networks – Bridges and Bridged Networks*.
https://standards.ieee.org/standard/802_1Q-2018.html
- [IEEE 802.3] IEEE 802.3-2018, *IEEE Standard for Ethernet*.
https://standards.ieee.org/standard/802_3-2018.html
- [IEEE 1588] IEEE 1588-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*.
<https://standards.ieee.org/standard/1588-2008.html>
- [IETF RFC 791] IETF RFC 791 (1981), *Internet Protocol (IP)*.
<http://www.ietf.org/rfc/rfc0791.txt?number=791>
- [IETF RFC 2460] IETF RFC 2460 (1998), *Internet Protocol, Version 6 (IPv6) Specification*.
<http://www.ietf.org/rfc/rfc2460.txt?number=2460>
- [IETF RFC 3031] IETF RFC 3031 (2001), *Multiprotocol Label Switching Architecture*.
<http://www.ietf.org/rfc/rfc3031.txt?number=3031>

3 Definitions

The terms and definitions used in this Recommendation are contained in [ITU-T G.810], [ITU-T G.8260] and [IEEE 1588].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

1PPS	One Pulse Per Second
ARP	Antenna Reference Point
BIPM	International Bureau of Weights and Measures
BBU	Base Band Unit
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CoMP	Co-ordinated Multi-Point
CRC	Cyclic Redundancy Check
CU	Centralized Unit
DCF	Dispersion Compensating Fibre
DU	Distributed Unit
eNB	E-UTRAN Node B
EN-DC	E-UTRAN New radio – Dual Connectivity
ERA	Earth Rotation Angle
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FCS	Frame Check Sequence
FDD	Frequency Division Duplexing
FR1	Frequency Range 1
FR2	Frequency Range 2
GBAS	Ground Based Augmentation System

GLONASS	GLObalnaya NAVigazionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GMT	Greenwich Mean Time
gNB	5G (NR) Node B
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HRM	Hypothetical Reference Model
HRPD	High Rate Packet Data
IP	Internet Protocol
IRNSS	Indian Regional Navigation Satellite System
IWF	Interworking Function
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MBSFN	MBMS based on Single Frequency Network
MIMO	Multiple Input Multiple Output
MRTD	Maximum Received Time Difference
M2M	Machine to Machine
NR	New Radio
NTP	Network Time Protocol
OTDOA	Observed Time Difference of Arrival
OTN	Optical Transport Network
PDV	Packet Delay Variation
PHY	Physical Layer Protocol
PON	Passive Optical Network
PRTC	Primary Reference Time Clock
PSN	Packet Switched Network
PTP	Precision Time Protocol
QZSS	Quasi-Zenith Satellite System
RTT	Radio Transmission Technology
RX	Receive
SBAS	Satellite Based Augmentation System
SI	International System of Units
SMTC	SSB Measurement Timing Configuration
SSB	Synchronization Signal Block
TAE	Time Alignment Error

TAI	International Atomic Time
TDD	Time Division Duplexing
TD-SCDMA	Time Domain Synchronized CDMA
T-BC	Telecom Boundary Clock
T-GM	Telecom Grandmaster
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Slave Clock
TX	Transmit
UDP	User Datagram Protocol
UE	User Equipment
UT	Universal Time
UTC	Universal Time Co-ordinated
UTRA	Universal Terrestrial Radio Access
WCDMA	Wideband CDMA
WDM	Wavelength-Division-Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access

5 Conventions

Within this Recommendation, the following conventions are used: The term precision time protocol (PTP) is the protocol defined by [IEEE 1588]. As an adjective, it indicates that the modified noun is specified in or interpreted in the context of [IEEE 1588].

6 The need for time and phase synchronization

Time synchronization has traditionally been required to support billing and alarm functions (maintenance or fault isolation). In this context, synchronization must in general be accurate to within hundreds of milliseconds.

Another time synchronization application is the monitoring of delays in Internet protocol (IP) networks. In this case, the requirement is accuracy to within some hundreds of microseconds (the actual requirement depends on the application).

Stringent time synchronization requirements (i.e., in the range of a few microseconds) apply to the generation of signals over the air interface of some mobile systems, such as code division multiple access (CDMA)2000 or long term evolution frequency division duplexing (LTE FDD) unicast, when it is required to support synchronous CDMA2000 interworking.

Phase synchronization is often needed to support requirements for the air interface of some mobile systems, as in the case of time division duplexing (TDD) systems (for instance, LTE TDD), or when supporting multimedia broadcast/multicast service (MBMS). Note that ordinary wideband CDMA (WCDMA) MBMS does not require accurate phase synchronization since it has been specified and designed to work properly in networks that satisfy the 50 ppb frequency accuracy requirement. This requirement, which is guaranteed by the WCDMA node synchronization function (see [b-3GPP TS 25.402]), limits phase drift to between 10 and 20 ms. But when MBMS is based on single-frequency network (MBSFN) mode, timing must be accurate to within a few microseconds. This is because identical waveforms are transmitted simultaneously from multiple cells. The signals from these cells are then combined as the multipath components of a single cell. Terminals must thus

perceive the signals of an entire group of transmitting cells as though they came from a single cell. Therefore, all transmissions must be very tightly synchronized and deliver exactly the same content to each base station.

The main requirements applicable at the output of the application (e.g., on the radio interface in the case of a wireless application) are summarized in Appendix II.

Based on Table II.1, it is possible to classify the applications into classes of requirements, as shown in Table 1 below.

NOTE – In the case of mobile applications as described in Table II.1, the requirements are generally expressed in terms of phase error between base stations. In the case of a centralized master, the requirement could be expressed as $\pm$ half of the accuracy requirement applicable to the specific technology. Table 1 presents the requirement in this format in order to allow the analysis of time error budgeting as distributed from a primary reference time clock (PRTC) towards the end application.

Table 1 – Time and phase requirement classes

Class level of accuracy	Time error requirements (Note 1)	Typical applications (for information)
1	500 ms	Billing, alarms.
2	100 – 500 μ s	IP delay monitoring. Synchronization signal block (SSB)-measurement timing configuration (SMTC) window.
3	5 μ s	LTE TDD (large cell). Synchronous Dual Connectivity (for up to 7 km propagation difference between eNBs/gNBs in FR1). (Note 2)
4	1.5 μ s	UTRA-TDD, LTE-TDD (small cell), NR TDD, WiMAX-TDD (some configurations). Synchronous dual connectivity (for up to 9 km propagation difference between eNBs/gNBs in FR1) (Note 2). New radio (NR) intra-band non-contiguous and inter-band carrier aggregation, with or without multiple input multiple output (MIMO) or transmit (TX) diversity.
5	1 μ s	WiMAX-TDD (some configurations).
6	x ns (Note 4)	Various applications, including location based services and some coordination features. (Note 3)

NOTE 1 – The requirement is expressed in terms of time error with respect to a common reference. Some of the original requirements were expressed in terms of relative time error.

NOTE 2 – FR1: 410 MHz – 7.125 GHz; FR2: 24.25 – 52.6 GHz

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

NOTE 4 – For the value x, refer to Table 2 and Table II.2 of Appendix II.

Based on Table II.2, it is possible to classify the class 6 level of accuracy into a further three sub-classes, as shown in Table 2.

Table 2 – Time and phase requirements for cluster based synchronisation

Class level of accuracy	Maximum relative time error requirements (Note 1)	Typical applications (for information)
3A	5 μ s	LTE MBSFN.
4A	3 μ s	NR intra-band non-contiguous (FR1 only) and inter-band carrier aggregation; with or without MIMO or TX diversity.
6A	260 ns	LTE intra-band non-contiguous carrier aggregation with or without MIMO or TX diversity, and inter-band carrier aggregation with or without MIMO or TX diversity. NR intra-band contiguous (FR1 only) and Intra-band non-contiguous (FR2 only) carrier aggregation, with or without MIMO or TX diversity.
6B	130 ns	LTE intra-band contiguous carrier aggregation, with or without MIMO or TX diversity. NR (FR2) intra-band contiguous carrier aggregation, with or without MIMO or TX diversity.
6C (Note 2)	65 ns	LTE and NR MIMO or TX diversity transmissions, at each carrier frequency.
NOTE 1 – The maximum relative time error requirements represent the largest timing difference measured between any two elements of the cluster. See Appendix VII of [b-ITU-T G.8271.1] for illustration of how requirements are specified in a cluster. In 3GPP terminology this is equivalent to time alignment error (TAE). NOTE 2 – Level 6C is an internal equipment specification, and does not result in a synchronization requirement on the transport network.		

This Recommendation deals mainly with the class 4, 5, and 6A levels of accuracy requirement, as indicated in Table 2.

7 Time and phase synchronization methods

Packet-based methods (typically using the network time protocol (NTP)) without timing support from the network are traditionally used to support applications with less strict time and phase synchronization requirements (class 1 according to Table 1).

This Recommendation focuses on applications corresponding to classes 4, 5, and 6 according to Table 1.

For these applications, the following options are considered in this Recommendation:

- a distributed primary reference time clock (PRTC) approach, implementing a global navigation satellite system (GNSS) receiver in the end application (a global positioning system (GPS) receiver, for example);
- packet-based methods with timing support of intermediate nodes.

NOTE 1 – Additional solutions may be considered as a complement to the above solutions. As an example, timing may be carried over the radio interface of mobile systems. Applicability to the general hypothetical reference model (HRMs) is for further study.

NOTE 2 – The use of packet-based methods with limited timing support, or without timing support of intermediate nodes, is considered capable of addressing applications corresponding to class 4.

The following clauses provide details on the synchronization methods based on the distributed PRTC approach, and packet based methods with timing support of intermediate nodes.

7.1 Distributed PRTC

One method to achieve time and phase synchronization is to distribute a synchronization signal directly to each clock in the network. This method is referred to as a distributed primary reference time clock and, in general, is feasible with radio distribution because a network-wide wire-based distribution would require a complete extra network, which may be impractical. However, in some cases, a remote distribution of the PRTC signal via cables might also be possible. The radio distribution is normally achieved by means of GNSS, as for instance the GPS. Other radio systems may also be used.

The main objective of a synchronization network is to synchronize the end applications which require a timing reference. If there are several end applications in one site, a single PRTC reference can be deployed in the site and the time/phase reference can be further distributed within the site from a centralized function. The details of the centralized function are for further study.

Figure 1 below gives a generic representation of the distributed PRTC method. In the case of GNSS-based synchronization, the reference timing signal is distributed by the satellite signals and the GNSS receiver acts as the PRTC of the network. The receiver (RX) in Figure 1 processes the GNSS signal and extracts a reference signal for the end applications.

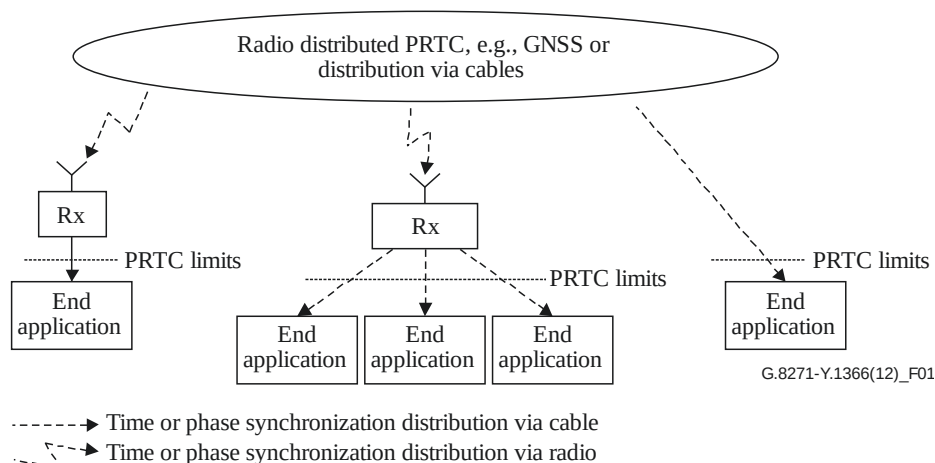


Figure 1 – Example of a distributed PRTC synchronization network

7.1.1 Main characteristics

One of the main advantages for a distributed PRTC approach is that the reference timing signals are available world-wide in the case of GNSS. This approach also allows for a flat distribution hierarchy with no risk of timing loops. In general, the overall network planning is also easier.

The main disadvantages of this approach are the dependency on the operator of the navigation system, the requirements for an antenna with a wide-angle view to the sky, the need to address lightning protection and, in general, the issues related to the antenna cabling.

Finally, GNSS-based systems present a risk of interference, e.g., by television (TV) systems, saturation and jamming.

It should be mentioned, however, that evolution of the technology reduces some of the main drawbacks (e.g., installation, reliability, etc.). Moreover, it should be possible to secure the GNSS

receivers, for instance when an accurate frequency reference, such as a synchronous Ethernet signal, is available. The options for securing GNSS receivers are for further study.

In terms of performance, the accuracy that can be achieved by means of a PRTC system is defined in [ITU G.8272].

7.2 Packet based methods with timing support of intermediate nodes

Time synchronization can be distributed via timing protocols such as PTP (see [IEEE 1588]). This Recommendation currently focuses on the cases where the timing reference is carried with support from the network.

The timing support in the intermediate nodes (e.g., Ethernet switches) concerns specific hardware as well as software timing functions (see Figure 2).

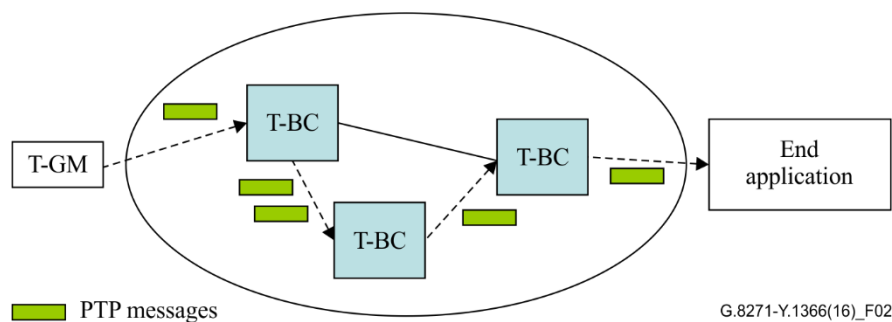


Figure 2 – Example of packet-based method with support from network nodes

In the case of PTP, these functions can correspond either to the telecom boundary clock (T-BC) or to the telecom transparent clock (T-TC), with hardware timestamping at the related interfaces.

The T-BC terminates and regenerates timestamp messages.

The T-TC provides a means of measuring the delays that have been added by the network element and by the links connected to the network element. This Recommendation considers only T-BC support in this version. The use of T-TC in telecom applications is for further study.

The Figure 3 shows an example of phase/time synchronization distributed via packet-based methods with timing support from the network. A packet master clock function in a telecom grandmaster (T-GM) having access to a reference timing signal compliant with the PRTC limits originates the packet timing distribution, and every transport node implements a T-BC.

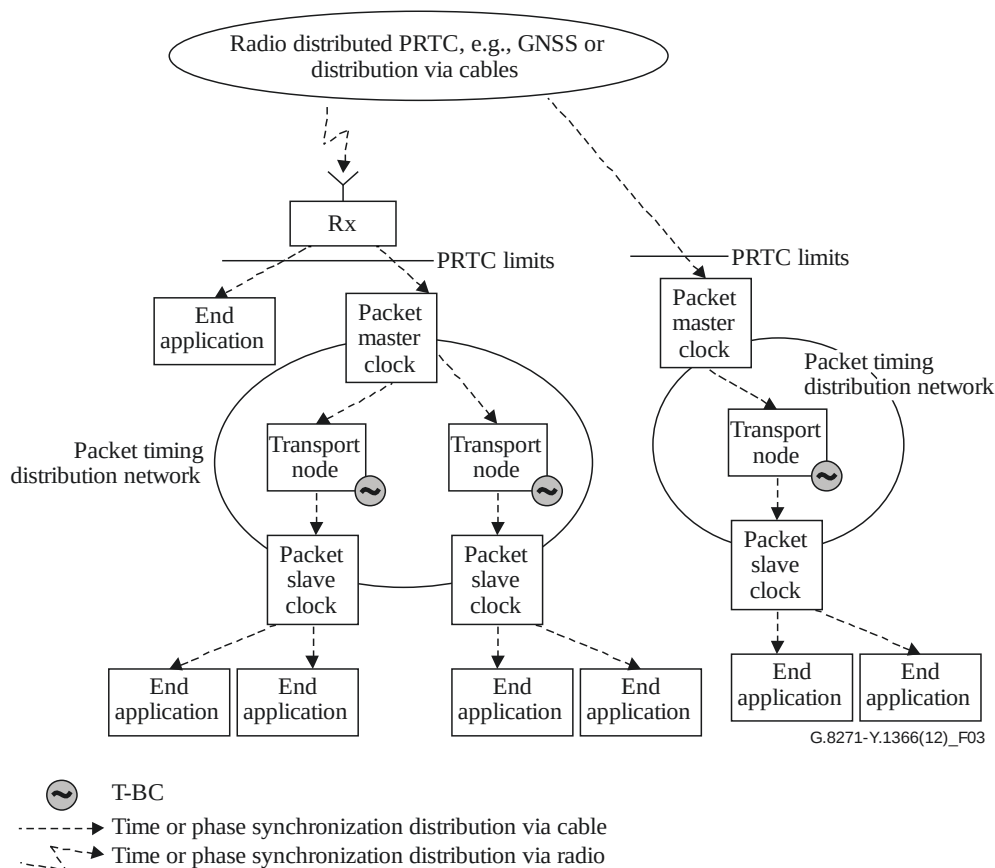


Figure 3 – Example of time synchronization distributed via packet based methods

7.2.1 Main characteristics

The main advantage of a time synchronization distribution solution via packet-based methods is the significantly reduced number of GNSS receivers. Note that if the PRTC is based on GNSS, then GNSS receivers would be required at the PRTC locations.

Among the disadvantages, it can be noted that the network planning is in this case more complex (e.g., with risk of timing loops). In addition, noise accumulation has also to be taken into account. Finally, another issue with this methodology is the time error due to asymmetries in the network that needs to be controlled (e.g., implying calibration of fibre lengths).

8 Network reference model

Figure 4 describes the network reference model used to define the time and phase synchronization performance objectives when the reference timing signal is carried over the transport network:

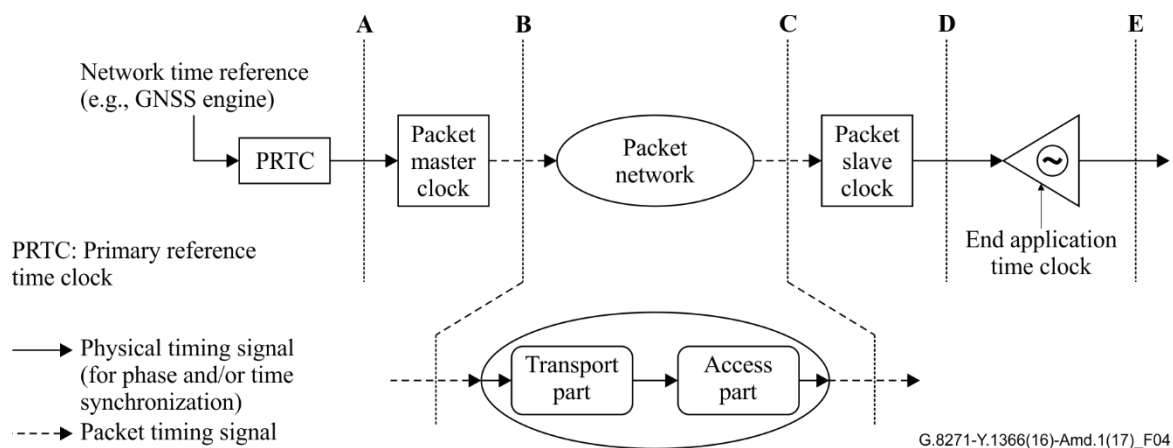


Figure 4 – Network reference model

The following reference points are defined. All the requirements related to these reference points are defined with respect to a common time reference, i.e., any recognized time reference such as GPS time.

- A: PRTC output;
- B: Packet master clock output;
- C: Packet slave clock input;
- D: Packet slave clock output;
- E: End application output.

Some specific access technologies may need to be considered in the network reference model in some cases. For instance, the network between points B and C can be composed in some cases of a transport part and an access part. Each part would then have its own phase/time budget derived from the media specific mechanisms that have been developed to transport frequency and time synchronization.

NOTE 1 – In Figure 4 the packet master clock could correspond to a T-GM and the packet slave clock could correspond to a telecom time slave clock (T-TSC).

NOTE 2 – The performance studies documented in [b-ITU-T G.8271.1] are based on a full timing support in the network with hardware timestamping (e.g., T-BC in every node in the case of [IEEE 1588]) and with physical layer frequency synchronization support (e.g., synchronous Ethernet support). The case of partial timing support, where some or all of the nodes are not capable of providing timing support to the PTP layer, is covered in [b-ITU-T G.8271.2].

NOTE 3 – In some cases, specific access technologies may need to be considered in the network reference model. For instance in some cases, the packet network between points B and C can be composed of a transport part and an access part. Each part would then have its own phase/time budget. In some radio access networks (RAN) scenarios, for instance when the RAN is split based on different radio functions, from the point of view of timing, the starting point for the RAN may be present between points B and C shown in Figure 4. Alternatively, the entire network model may be present within the RAN. Details are for further study.

NOTE 4 – Additional detail for the network reference model of Figure 4 for the case of PTP over non-packet technologies (e.g., OTN, gigabit passive optical network (GPON), microwave) is for further study.

The overall budget relates to measurement point 'E' (i.e., the time error at E with respect to the common time reference).

'A', 'B', 'C' and 'D' define the other relevant measurement reference points and related network limits, that also indicate the budget of the noise that can be allocated to the relevant network segments (e.g., 'A to C', 'A to D', etc.).

The measurement points that are of interest for a specific application may depend on where the network administrative domain borders apply.

Also, as described above, the measurement in some cases needs to be performed on a two-way timing signal, which would require a specific test set-up and metrics to be used.

The measurement set-up for two-way timing signals as well as the noise that can be added by the measurement test equipment is an item for further study.

Another possibility is to perform the measurement using an external dedicated output phase/time reference, such as a one pulse per second (1PPS) interface. Annex A provides guidance about this type of interface.

8.1 Access section of HRM with PTP/native access IWF

The general network reference model in Figure 4 can be further expanded to illustrate different types of access technology that may be used at the edge of the network such as microwave, digital subscriber line (DSL) or passive optical network (PON).

Generally access technologies can be categorized as either point-to-multipoint shared technologies or point-to-point technologies. An example of a point-to-multipoint shared media technology is a PON with a single multi-port head end and multiple end devices. An example of a point to point technology is a microwave system. Figure 5 expands the access section to show the media conversion that occurs between the Ethernet technology that forms the existing synchronization HRM of the transport section and the technologies in the access section of the HRM. The time error budget of this section may depend on the specific type of technology.

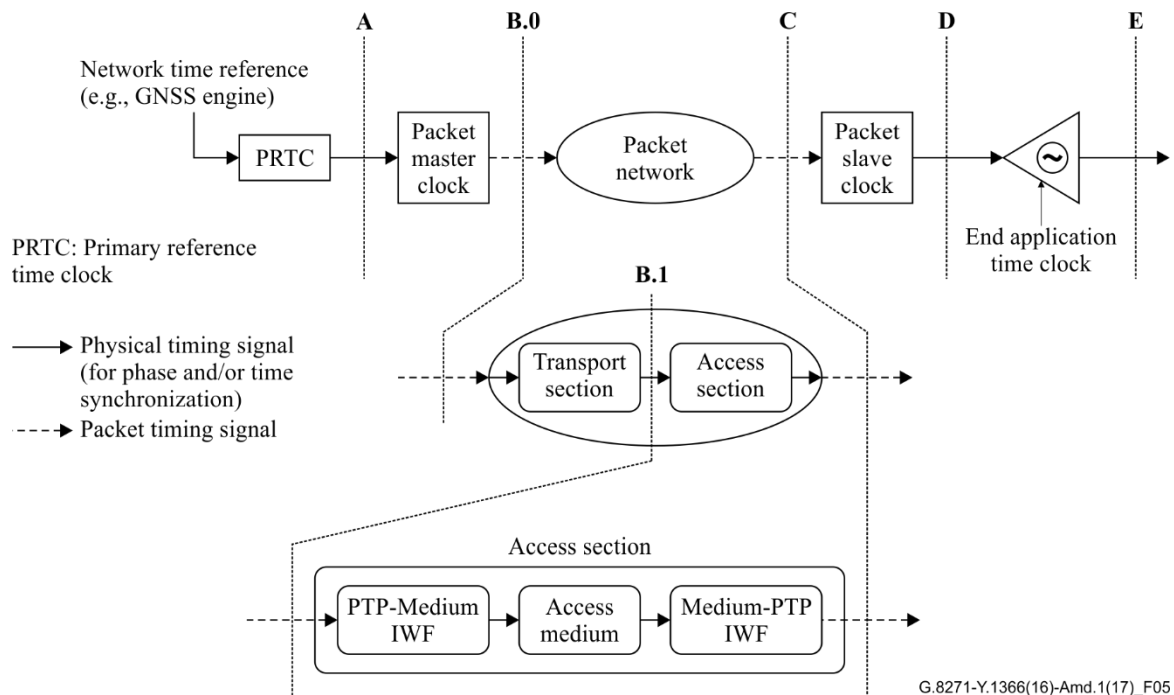


Figure 5 – Network reference model with access section

For example, between B.0 and B.1 the transport section consists of a network chain from [b-ITU-T G.8271.1] comprised of full timing aware ITU-T G.8273.2 T-BCs using PTP & SyncE. Between B.1 and C of the access section, there may also be T-BCs, and in this case they are connected to and from native access clocks. These native access clocks provide the direct connection to the medium. Essentially, the T-BC and native access clock provides an interworking function (IWF) that converts between Ethernet carrying PTP and the access medium.

The access section will have a time error that is a combination of the constant and dynamic components of the medium as well as contribution from the clocks in the access section.