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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

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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.

This 2017 edition of the Recommendation integrates G.8271/Y.1366 (2016) Amd.1 (2017) into the base text. It does not add any new technical content.

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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]).
- MPLS ([IETF RFC 3031] and [ITU-T G.8110]).
- IP ([IETF RFC 791] and [RFC 2460]).
- OTN ([ITU-T G.709]).

The physical layers that are relevant to this specification are the Ethernet media types, as defined in [IEEE 802.3] and, for OTN, the Optical OCh layer with 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), *Physical/electrical characteristics of hierarchical digital interfaces*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2016), *Interfaces for the optical transport network*.

[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] Recommendation ITU-T G.8261/Y.1361 (2013*), Timing and synchronization aspects in packet networks.*

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

[ITU-T V.11] Recommendation ITU-T V.11/X.27 (1996), *Electrical characteristics for balanced double-current interchange circuits operating at data signalling rates up to 10 Mbit/s.*

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[IEEE 802.1Q] IEEE 802.1Q-2014, *IEEE Standard for Local and metropolitan area networks – Bridges and Bridged Networks* <http://standards.ieee.org/findstds/standard/802.1Q-2014.html>

[IEEE 802.3] IEEE 802.3-2015, *IEEE Standard for Ethernet*. <http://standards.ieee.org/findstds/standard/802.3-2015.html>

[IEEE 1588] IEEE 1588-2008, *Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*. <http://standards.ieee.org/findstds/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
CDMA	Code Division Multiple Access
DCF	Dispersion Compensating Fibre
FCS	Frame Check Sequence
FDD	Frequency Division Duplex
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HRPD	High Rate Packet Data
IP	Internet Protocol
IRNSS	Indian Regional Navigation Satellite System
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
M2M	Machine to Machine
NTP	Network Time Protocol
OTN	Optical Transport Network
PDV	Packet Delay Variation

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PHY	Physical Layer Protocol
PRTC	Primary Reference Time Clock
PSN	Packet Switched Network
PTP	Precision Time Protocol
QZSS	Quasi-Zenith Satellite System
RTT	Radio Transmission Technology
SBAS	Satellite Based Augmentation System
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
UDP	User Datagram Protocol
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 CDMA2000 or 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 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

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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 ± 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

Level of accuracy	Time error requirements (Note 1)	Typical applications (for information)
1	500 ms	Billing, alarms
2	100 µs	IP Delay monitoring Asynchronous Dual Connectivity
3	5 µs	LTE TDD (large cell) Synchronous Dual Connectivity (for up to 7 km propagation difference between eNodeBs)
4	1.5 µs	UTRA-TDD, LTE-TDD (small cell) WiMAX-TDD (some configurations) Synchronous Dual Connectivity (for up to 9 km propagation difference between eNodeBs)
5	1 µs	WiMAX-TDD (some configurations)
6	x ns (Note 3)	Various applications, including 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 µs 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 – 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.

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Table 2 – Time and phase requirements for cluster based synchronisation

Level of accuracy	Maximum Relative Time error requirements (Note)	Typical applications (for information)
6A	260 ns	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
6B	130 ns	Intra-band contiguous carrier aggregation, with or without MIMO or TX diversity
6C	65 ns	MIMO or TX diversity transmissions, at each carrier frequency
NOTE – The maximum relative time error requirements represent the peak-to-peak time difference measured between the elements in the cluster only. See Appendix VII of [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), which is defined as the largest timing difference between any two signals.		

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 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 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.

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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 the figure) processes the GNSS signal and extracts a reference signal for the end applications.

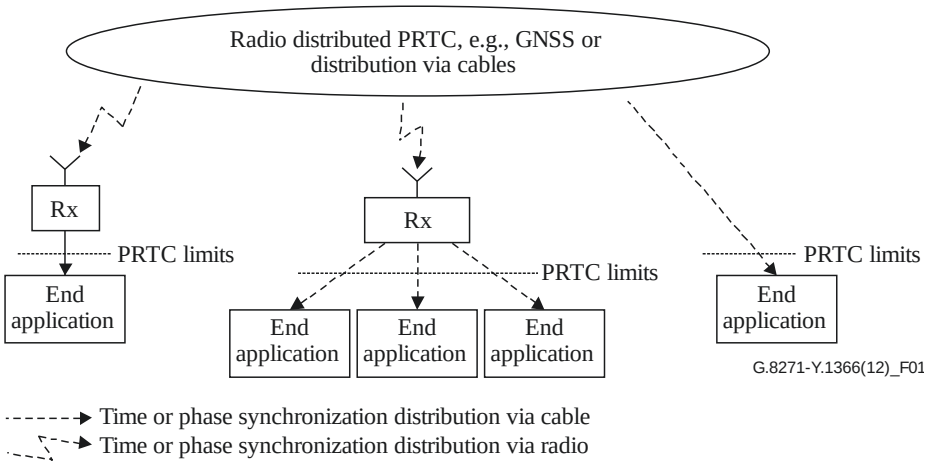

Figure 1 – Example of a distributed PRTC synchronization network

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 TV systems, saturation, and jamming.

It should, however, be mentioned 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].

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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).

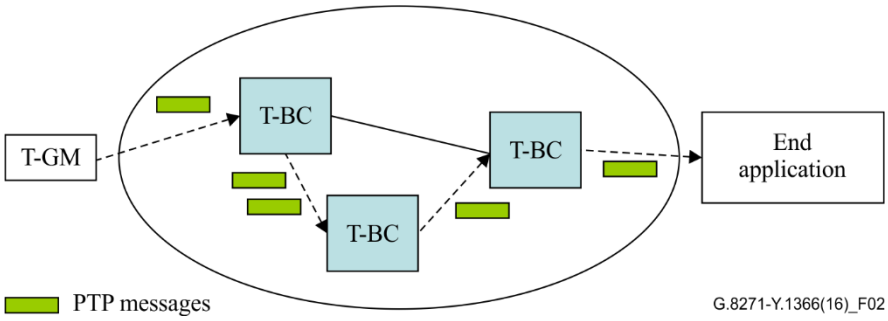

Figure 2 – Example of packet-based method with support from network nodes

In the case of PTP, these functions can correspond either to the T-BC or to the 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 following figure 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 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.

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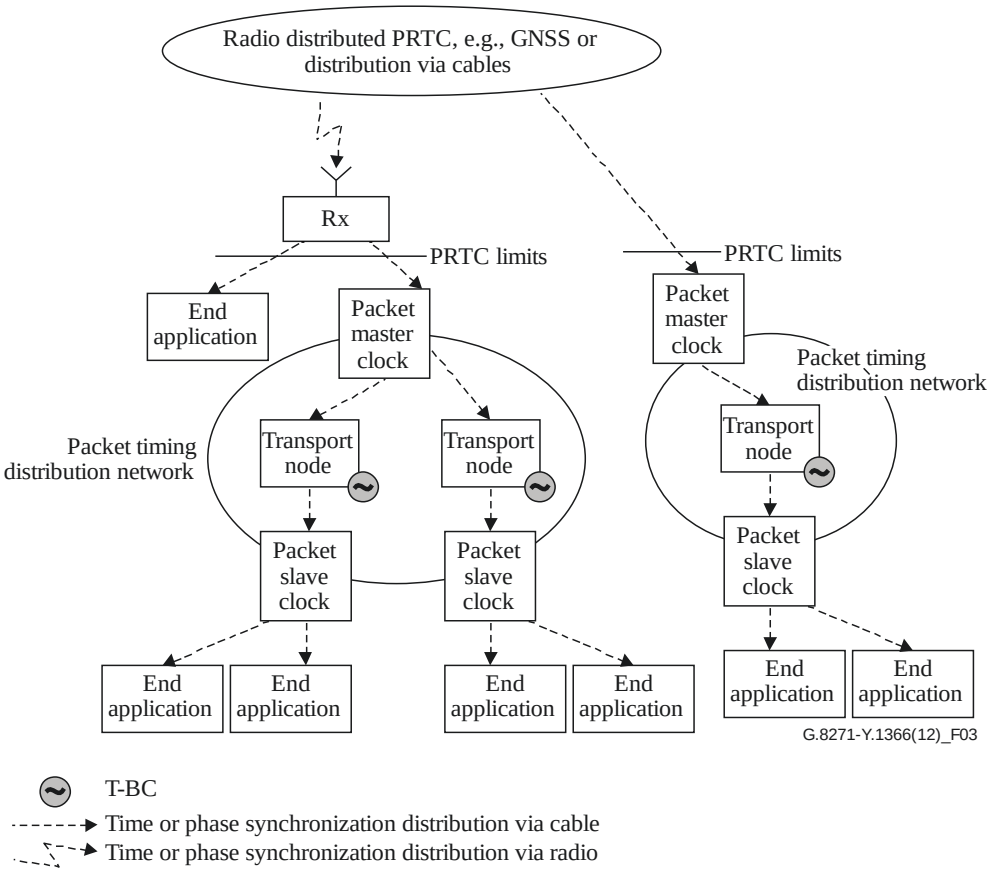

Figure 3 – Example of time synchronization distributed via packet based methods

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:

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