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

Packet over Transport aspects – Quality and availability targets

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS AND NEXT-GENERATION NETWORKS

Internet protocol aspects – Transport

Time and phase synchronization aspects of packet networks

Recommendation ITU-T G.8271/Y.1366

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Recommendation ITU-T G.8271/Y.1366

Time and phase synchronization aspects of packet 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.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.8271/Y.1366	2012-02-13	15

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

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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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had not 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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Time and phase synchronization aspects of packet networks

1 Scope

This ITU-T Recommendation 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. It also specifies the relevant time and phase synchronization interfaces and related performance.

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

- Ethernet ([IEEE 802.3], [IEEE 802.1D], [IEEE 802.1ad], [IEEE 802.1Q], and [IEEE 802.1Qay]).
- MPLS ([IETF RFC 3031] and [ITU-T G.8110]).
- IP ([IETF RFC 791] and [RFC 2460]).

The physical layer that is relevant to this specification is the Ethernet media types, as defined in IEEE Standard 802.3-2005.

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 (2012), *Definitions and terminology for synchronization in packet networks.*

[ITU-T G.8261] Recommendation ITU-T G.8261/Y.1361 (2008*), Timing and synchronization aspects in packet networks.*

[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.*

[IEEE 802] IEEE 802-2001, *IEEE standard for local and metropolitan area networks: Overview and architecture*.
<http://standards.ieee.org/getieee802/802.html>

[IEEE 802.1D] IEEE 802.1D-2004, *IEEE Standard for local and metropolitan area networks: Media Access Control (MAC) Bridge*s.
<http://standards.ieee.org/getieee802/download/802.1D-2004.pdf>

[IEEE 802.1Q] IEEE 802.1Q-2005, *IEEE Standard for local and metropolitan area networks: Virtual bridged local area network*s.
<http://standards.ieee.org/getieee802/download/802.1Q-2005.pdf>

[IEEE 802.1ad] IEEE 802.1ad-2005, *IEEE Standard for local and metropolitan area networks: Virtual bridged local area networks – Amendment 4: Provider Bridges*.
<http://standards.ieee.org/getieee802/download/802.1ad-2005.pdf>

[IEEE 802.3] IEEE 802.3-2008, *Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*.
<http://standards.ieee.org/getieee802/802.3.html>

[IEEE 1588-2008] IEEE Std 1588-2008, *Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*.
<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4579760>.

[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 1588-2008].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

1PPS One Pulse Per Second

CDMA Code Division Multiple Access

EEC Ethernet Equipment Clock

FDD Frequency Division Duplex

GNSS Global Navigation Satellite System

GPS Global Positioning System

HRPD High Rate Packet Data

HRM Hypothetical Reference Model

IP Internet Protocol

LTE Long Term Evolution

MBMS Multimedia Broadcast Multicast Service

MBSFN MBMS based on Single Frequency Network

NTP Network Time Protocol

PDV Packet Delay Variation

PHY Physical Layer Protocol

PRTC Primary Reference Time Clock

PTP Precision Time Protocol

RTT Radio Transmission Technology

SCDMA Synchronized CDMA

SSU	Synchronization Supply Unit
TDD	Time Division Duplexing
T-BC	Telecom Boundary Clock
T-GM	Telecom Grandmaster
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Slave Clock
WCDMA	Wideband CDMA
WDM	Wavelength-Division-Multiplexing

5 Conventions

Within this Recommendation, the following conventions are used: The term precision time protocol (PTP) is the protocol defined by [IEEE 1588-2008]. As an adjective, it indicates that the modified noun is specified in or interpreted in the context of [IEEE 1588-2008].

The term telecom boundary clock (T-BC) is a device consisting of a boundary clock as defined in [IEEE1588-2008] and with additional performance characteristics for further study.

The term telecom transparent clock (T-TC) is a device consisting of a transparent clock as defined in [IEEE1588-2008] and with additional performance characteristics for further study.

The term telecom grandmaster (T-GM) is a device consisting of a grandmaster clock as defined in [IEEE1588-2008] and with additional performance characteristics for further study.

The term telecom time slave clock (T-TSC) is a device consisting of a PTP slave only ordinary clock as defined in [IEEE1588-2008] and with additional performance characteristics for further study.

6 The need for phase and time 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 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 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 is guaranteed by the WCDMA node synchronization function (see [b-ETSI TS 125 402]), 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 applications into classes of requirements, as shown in Table 1 below.

Table 1 – Time and phase requirement classes

Level of accuracy	Range of requirements (Note 2)	Typical applications
1	1 ms-500 ms	Billing, alarms
2	5 µs-100 µs (Note 1)	IP Delay monitoring
3	1.5 µs-5 µs	LTE TDD (large cell) Wimax-TDD (some configurations)
4	1 µs-1.5 µs	UTRA-TDD, LTE-TDD (small cell)
5	x ns-1 µs (Note 4)	Wimax-TDD (some configurations)
6	< x ns (Note 4)	Some LTE-A features (Note 3)

NOTE 1 – The most stringent requirement that is expected for IP monitoring has been chosen as the limit for this class of requirements.

NOTE 2 – The requirement is expressed in terms of error with respect to the ideal reference.

NOTE 3 – The performance requirements of the LTE-A features are under study.

NOTE 4 – The value for x is for further study.

This Recommendation deals mainly with the more stringent classes of requirements, indicated as levels of accuracy 4, 5, and 6 in Table 1.

7 Time-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 GPS receiver, for example).
- Packet-based methods with timing support of intermediate nodes.

NOTE – The use of packet-based methods without timing support of intermediate nodes, and the definition of which class of requirements in Table 1 they can support, are for further study.

The following clauses provide details on the characteristics for the different synchronization methods.

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.

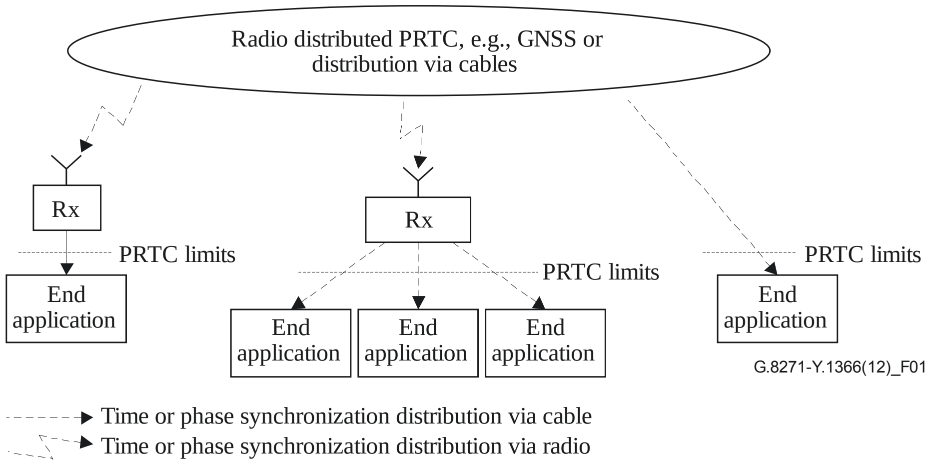


Figure 1 – Example of a distributed PRTC synchronization network

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 for further study.

7.2 Packet based methods with timing support of intermediate nodes

Time synchronization can be distributed via timing protocols such as PTP (see [IEEE 1588-2008]). 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).

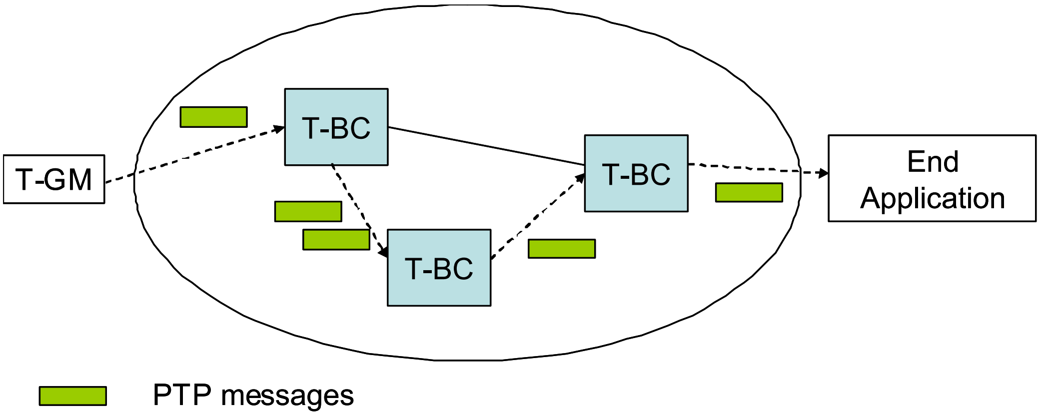


Figure 2 – Example of packet-based method with support from network nodes

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.

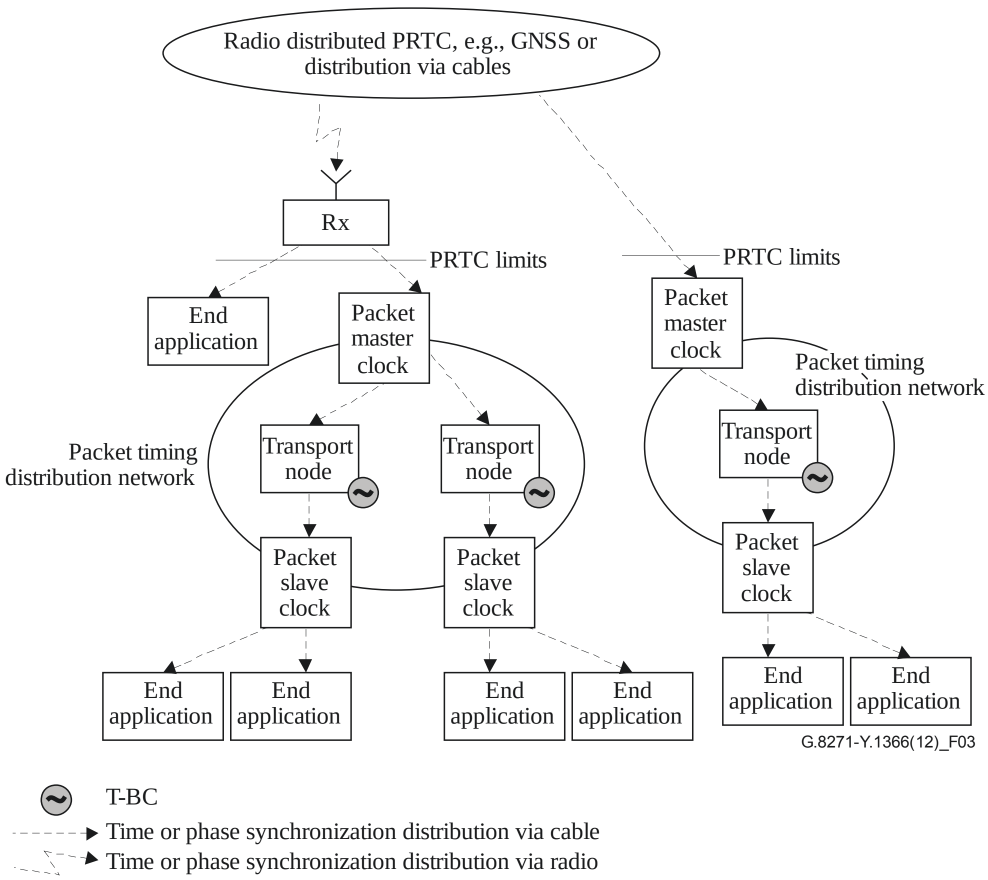


Figure 3 – Example of time synchronization distributed via packet based methods

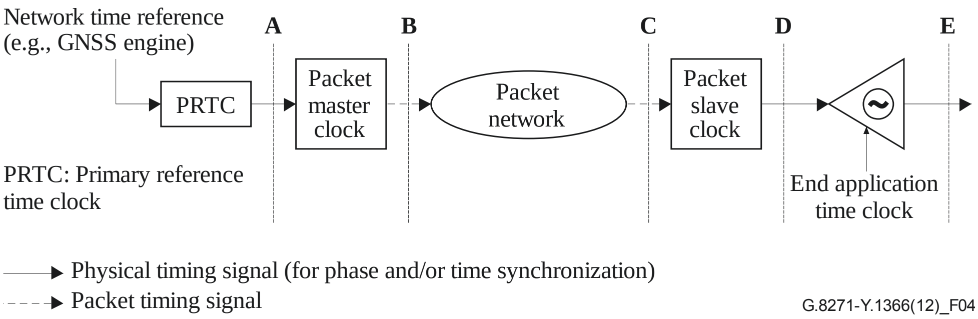
Main characteristics

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.



A: PRTC network limits
B: Packet master clock network limits
C: Packet slave clock input network limits
D: Packet slave clock output network limits (if applicable)
E: End application requirements (e.g., phase accuracy)

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 network limits, i.e., the network limits applicable at the output of the PRTC. In this case, the requirement is applicable to a dedicated timing signal interface (e.g., 1PPS, that may also be combined with ToD information).
- B: Packet master clock network limits, i.e., the network limits applicable at the output of the packet master clock. In this case, the requirement is applicable to a packet timing signal.
- C: Packet slave clock input network limits. In this case, the requirement is applicable to a packet timing signal.
- D: Packet slave clock output network limits. In this case the requirement is applicable to the recovered reference timing signal. This reference point is not applicable in the case of a packet slave clock integrated in the end application.
- E: End-application output requirement, e.g., radio interface in the case of base stations.

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

NOTE 2 – The performance studies under development are based on a full timing support in the network with hardware timestamping (e.g., T-BC in every node in the case of IEEE1588-2008) with and without physical layer frequency synchronization support (e.g., synchronous Ethernet support).

The case of partial timing support is for further study.

The overall budget is related at 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, and that also indicates the budget of the noise that can be allocated to the relevant network segments (e.g., 'A' to 'C', 'A' to 'D', etc.).

NOTE 3 – Some specific access technologies may need to be considered in the network reference model in some cases. For instance, the packet 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. In other scenarios, the access segment can be positioned at point D, between the packet slave clock and the end application. The definition of network reference models considering the access technologies is for further study.

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

As also described above, the measurement in some cases needs to be performed on a two-way timing signal that 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 1PPS interface. Annex A in this Recommendation provides guidance about this type of interface.

9 Phase/time synchronization interfaces

Phase/time synchronization interfaces are needed for the following purposes:

1) Measurement interface:

   In order to allow network operators to measure the quality of the phase/time synchronization distributed along a synchronization chain, each PRTC, T-GM, T-BC and T-TSC must have a dedicated external phase/time output interface implemented.

   A one pulse-per-second (1PPS) interface is an adequate measurement interface, and should be implemented according to one of the interfaces specified in the Annex A of this Recommendation. Additional measurements interfaces are for further study.

2) Distribution interface:

   Phase/time synchronization interfaces are sometimes needed to connect systems belonging to a phase/time synchronization distribution chain.

   A typical application is the case of a T-TSC connected to an end-application, such as a base station, which is equipped with an existing input 1PPS interface. The details of the distribution interfaces are for further study.

Figure 5 shows examples of both types of phase/time synchronization interfaces: measurement interfaces (reference point 1) and distribution interfaces (reference point 2). Different requirements may apply to these points.

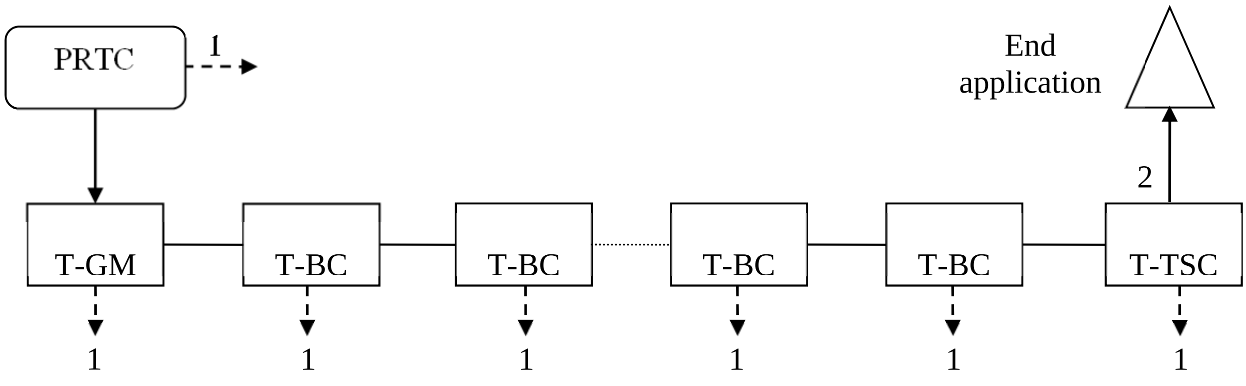


Figure 5 – Possible locations of external phase/time interfaces in a chain of Telecom-Boundary Clocks

Annex A

One pulse-per-second (1PPS) phase and time synchronization interface specification

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

A.1 ITU-T V.11 interface

The one pulse-per-second (1PPS) time/phase interface uses a point-to-point ITU-T V.11 interface as specified in [ITU-T V.11] with an additional requirement on the rise/fall times of the 1PPS signal. This is needed to provide the accuracy required for the 1PPS signal.

This interface can be used for time synchronization distribution as well as for time measurement.

The interface is a balanced interface that can tolerate significant common mode noise.

A.1.1 Interface signals

- 1PPS_OUT+/1PPS_OUT-: This output signal pair indicates the significant event occurring on the leading edge of the signal and is generated by the time master.
- 1PPS_IN+/1PPS_IN-: This input signal pair indicates the significant event occurring on the leading edge of the signal and is used by the time slave.
- TX+/TX-: This output signal pair is used for a serial communication channel for transfer of time messages and status messages between the time master and the time slave.
- RX+/RX-: This input signal pair is used for a serial communication channel for transfer of messages between the time master and the time slave.

The protocol used on the serial communication channel is for further study.

The connection requires the use of a crossed cable that connects the signal pairs as specified in Table A.1.

Table A.1 – Cable connections

Connector A	Connector B
1PPS_OUT+/1PPS_OUT-	1PPS_IN+/1PPS_IN-
1PPS_IN+/1PPS_IN-	1PPS_OUT+/1PPS_OUT-
TX+/TX-	RX+/RX-
RX+/RX-	TX+/TX-
NOTE – It may be that not all the signals in Table A.1 will be needed at the same time (e.g., one direction only might be sufficient in some cases). The backward direction of the messaging channel is for further study.	

A.1.2 1PPS rise and fall time specification

The maximum rise and fall times of the 1PPS_OUT signal pair at the output port, as specified in clause 5.3 of [ITU-T V.11], are for further study.

A.1.3 Signal timing

The time master must generate a positive pulse on the 1PPS signal such that the midpoint of the leading edge of the differential ITU-T V.11 signal at the edge of the chassis occur at the change of the one second time of the system. The positive pulse width must be between 200 ns and 500 ms.

NOTE – Internal delays in the equipment need to be compensated both at the transmitting and receiving sides in order to ensure that the 1PPS signal output timing accuracy requirement, as stated in Table A.2, is met.

The cable delays of the 1PPS signal must be controlled and compensated if needed in the receiving side, so as to meet the requirements stated in Table A.2. This may be done either manually by the network operator or automatically by the equipment.

Table A.2 – Timing budget for normal 1PPS interface

Parameter	Tolerance	Reference
1PPS signal generation accuracy of the timing master	For further study	
Cable delay compensation accuracy	For further study	From connector to connector with an ITU-T V.11 pulse.
1PPS signal detection accuracy at the slave	For further study	

A.2 1PPS 50 Ω phase synchronization measurement interface

A.2.1 Introduction

The 1PPS interface consists of an unbalanced 50-ohm 1PPS signal that can be used to connect to measurement equipment.

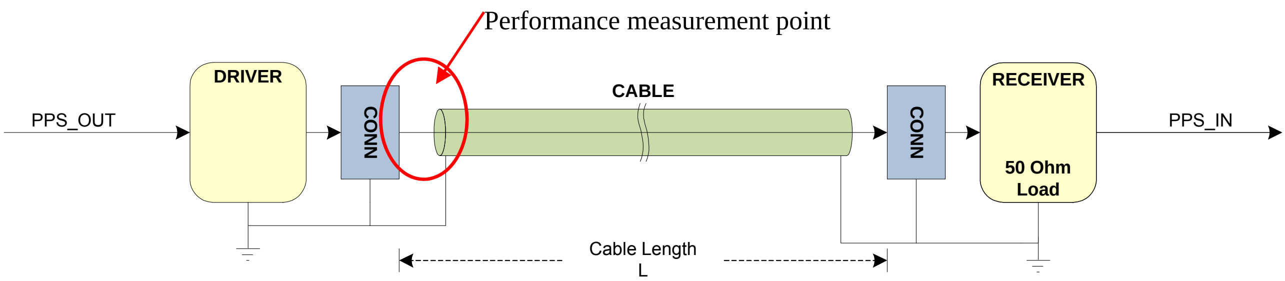


Figure A.1 – Unbalanced 1PPS 50-Ω measurement interface

A.2.2 Performance specification

This signal indicates the significant event occurring on the midpoint of the leading edge of the signal.

The system must generate a positive pulse on the 1PPS signal such that the midpoint of the leading edge of the signal at the edge of the chassis occurs at the one second roll-over of the system.

The pulse width must be between 100 ns and 500 ms.

The 10-90% rise times of the 1PPS pulse should be < 5 ns.

The system must compensate for the internal delays in the system to ensure that the 1PPS signal timing is met at the edge of the box.

The measurement equipment is expected to compensate for the delays associated with the interconnection of the 1PPS interface.

This interface is intended to be used with an impedance controlled 50 ohm cable with a maximum length of three meters to keep the influence of delay and rise time low.

Table A.3 – Timing specification for 1PPS measurement interface

Parameter	Tolerance	Reference
1PPS signal generation accuracy of the timing master	±5 ns	Measured at the 50% amplitude level
Maximum cable length	3 m	Due to delay and rise time performance

A.2.3 Additional information

For information, Table A.4 gives voltage levels for the interface.

Table A.4 – Output voltage levels

Interface	VOH (max)	VOH (min)	VOL (max)	VOL (min)
1PPS (50 ohm single-ended)	5.5 V	1.2 V	0.3 V	–0.3 V
NOTE – Measured with a 50 ohm load to ground.				

Appendix I

Time and phase noise sources in time distribution chains

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

Quantifying the sources of errors in the time distribution chain is essential in the process to defining noise budget in the network reference model.

The sources of errors listed in this appendix are based on a network with full timing support provided by telecom boundary clocks (T-BCs).

In the case of no timing support in some of the nodes, (or in all the nodes), additional sources of noise should be considered. This is for further study.

The sources of noise due to timing support provided by telecom transparent clocks (T-TCs) are also for further study.

I.1 Noise introduced by a primary reference time clock (PRTC)

The table below provides the sources of errors in a PRTC.

	Source of error	Explanation/Assumptions
1	Reference time error	See clause I.7.1

I.2 Noise introduced by a packet master clock function

The table below provides the sources of errors in a packet master clock function. The packet master clock function may be a part of a telecom grandmaster (T-GM) or a T-BC.

	Source of error	Explanation/Assumptions
1	PHY latency asymmetry internal to the nodes	See clause I.7.2

I.3 Noise introduced by a packet slave clock function

The table below provides the sources of errors in a packet slave clock function. The packet slave clock function may be part of a telecom time slave clock (T-TSC) or a T-BC.

	Source of error	Explanation/Assumptions
1	Local oscillator phase noise	See clause I.7.4
2	PHY latency asymmetry internal to the nodes	See clause I.7.2
3	Timestamping granularity	See clause I.7.3
4	Frequency reference phase error	See clause I.7.5
5	Time transients	See clause I.7.6

I.4 Noise introduced by a telecom transparent clock

The sources of error in a telecom transparent clock are for further study.

I.5 Noise introduced by a link

The table below provides the sources of errors in a link.

	Source of error	Explanation/Assumptions
1	Link asymmetry	See clause I.7.7

I.6 Derivation of delay asymmetry

Figure I.1 illustrates the delays between a packet slave clock function, or requestor (denoted as slave throughout this clause), and a packet master clock function, or responder (denoted as master throughout this clause). The mean propagation delay is measured at the slave after exchange of event messages. If the Delay Request and the Delay Response mechanism is used (see [IEEE 1588-2008]), the slave sends Delay_Req and the master sends Delay_Resp and, separately, Sync and Follow_Up (i.e., the sending of Sync and Follow_Up are not part of the Delay_Req/Delay_Resp exchange; the Follow_Up message is sent if, and only if, the clock is two-step). If the Peer Delay mechanism is used (see [IEEE 1588-2008]), the slave sends Pdelay_Req and the master sends Pdelay_Resp and, if the clock is two-step, Pdelay_Resp_Follow_Up.

The figure shows the effective points in the protocol stack of each clock where timestamps are generated, after any corrections for ingress and egress latencies are made (see clause 7.3.4 and Figure 19 of [IEEE 1588-2008]). These points would ideally be at the reference plane, i.e., the boundary point between the PHY and the network physical medium. However, in practice, the corrections for ingress and egress latencies are not perfect, and the effective points at which the timestamps are generated differ from the reference plane. The delays between the effective points where timestamps are taken and the reference plane are denoted $d_{tx}^{PHY,M}$ and $d_{rx}^{PHY,M}$ for egress and ingress, respectively, at the master, and $d_{tx}^{PHY,S}$ and $d_{rx}^{PHY,S}$ for egress and ingress, respectively, at the slave. In this notation, the subscript t (transmit) is used for egress and the subscript r (receive) is used for ingress. In general, these four quantities can all be different.

The figure also shows the link delays, which are measured from the reference plane of one clock to the reference plane of the other clock. The delay from the master to the slave is denoted d_{ms}^{link}, and the delay from the slave to the master is denoted d_{sm}^{link}.

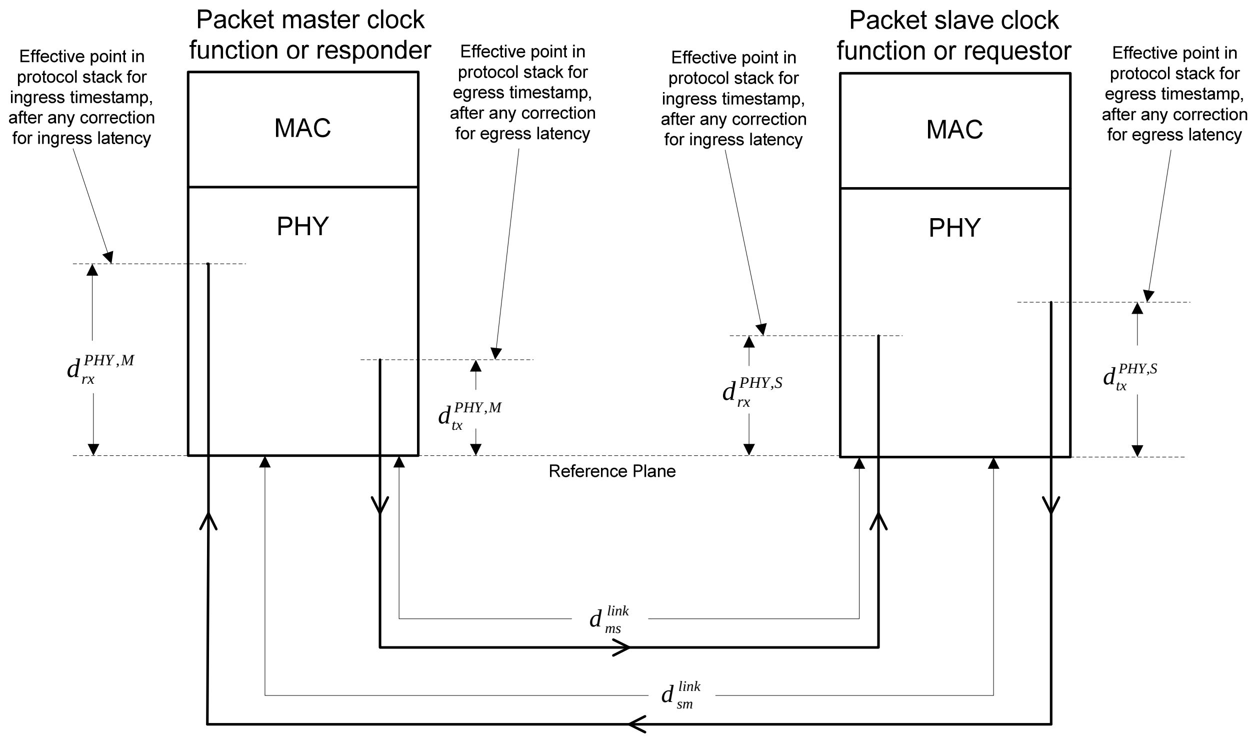


Figure I.1 – Illustration of delays between a packet slave clock function, or requestor, and a packet master clock function, or responder

The total delay from the master to the slave, t_{ms}, is the sum of the delays in that direction

$$t_{ms} = d_{tx}^{PHY,M} + d_{ms}^{link} + d_{rx}^{PHY,S} \tag{I-1}$$

Similarly, the total delay from the slave to the master, t_{sm}, is the sum of the delays in that direction

$$t_{sm} = d_{tx}^{PHY,S} + d_{sm}^{link} + d_{rx}^{PHY,M} \tag{I-2}$$

For the sign convention for the delay asymmetry, the same convention as in section 7.4.2 of [IEEE 1588-2008] is adopted. Let D_{mean} denote the measured mean path delay (i.e., the measured result of the exchange of Delay_Req and Delay_Resp or of Peer Delay messages), and D_{asym} denote the total delay asymmetry. Then, D_{asym} is defined to be positive when the delay from the master to the slave is larger than the delay from the slave to the master. Likewise, D_{asym} is defined to be negative when the delay from the master to the slave is smaller than the delay from the slave to the master . Then

$$\begin{aligned} t_{ms} &= D_{mean} + D_{asym} \\ t_{sm} &= D_{mean} - D_{asym} \end{aligned} \tag{I-3}$$

Equations (I-3) imply that

$$D_{mean} = \frac{t_{ms} + t_{sm}}{2} \tag{I-4}$$

as required. Substituting equations (I-1) and (I-2) into equation (I-4) gives

$$D_{mean} = \frac{(d_{tx}^{PHY,M} + d_{ms}^{link} + d_{rx}^{PHY,S}) + (d_{tx}^{PHY,S} + d_{sm}^{link} + d_{rx}^{PHY,M})}{2} \tag{I-5}$$

Either of the two equations (I-3) may be used with equation (I-4) to obtain the delay asymmetry in terms of the component delays. Using the first of equations (I-3) produces

$$
\begin{aligned}
D_{asym} &= t_{ms} - D_{mean} \\
&= (d_{tx}^{PHY,M} + d_{ms}^{link} + d_{rx}^{PHY,S}) - \frac{(d_{tx}^{PHY,M} + d_{ms}^{link} + d_{rx}^{PHY,S}) + (d_{tx}^{PHY,S} + d_{sm}^{link} + d_{rx}^{PHY,M})}{2} \\
&= \frac{d_{tx}^{PHY,M} - d_{rx}^{PHY,M}}{2} + \frac{d_{ms}^{link} - d_{sm}^{link}}{2} + \frac{d_{rx}^{PHY,S} - d_{tx}^{PHY,S}}{2} \\
&= e_{phy}^{M} + e_{link-asym} - e_{phy}^{S}
\end{aligned} \tag{I-6}
$$

where

$$e_{phy}^{M} = \frac{d_{tx}^{PHY,M} - d_{rx}^{PHY,M}}{2} \tag{I-7}$$

$$e_{link-asym} = \frac{d_{ms}^{link} - d_{sm}^{link}}{2} \tag{I-8}$$

$$e_{phy}^{S} = \frac{d_{tx}^{PHY,S} - d_{rx}^{PHY,S}}{2} \tag{I-9}$$

Equations (I-7) and (I-9) are the errors due to PHY latency asymmetry at the master and slave respectively. Equation (I-8) is the error due to link asymmetry. Equation (I-6) indicates that, in computing the total asymmetry, the errors due to PHY latency at the master and due to the link are added, while the error due to PHY latency at the slave is subtracted.

In order to compensate for link delay asymmetry, it might be desirable to have in place some automatic link asymmetry calibration procedure. This could be based on calculating the propagation delays by means of two-way measurements made on the fibres used by the traffic.

The procedure has to be done separately on both fibres (in the fibre used in the forward direction and in the fibre used for the reverse direction) providing the forward propagation delay d_f and the reverse propagation delay d_r (see Figure I.2).

NOTE 1 – In the case of the connection between master and slave, as shown in Figure I.1, the following would apply:

$d_f = d_{ms}$

$d_r = d_{sm}$

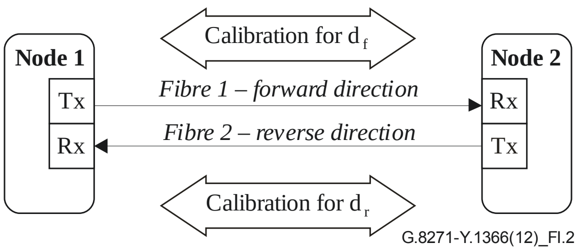


Figure I.2 – Link asymmetry calibration process

The link asymmetry calibration mechanism must meet an accuracy objective for d_f and d_r estimations. This limit is for further study.

Several implementations are possible, e.g., based on optical switches or fixed or tunable add drop filters. Depending on the implementation, it may not be required to interrupt the traffic during the calibration process, and hence in-service operation might be possible. However, the asymmetry compensation is a process only required at start-up or during rearrangements in the network.

This measurement is applicable for WDM systems (including OTN) and non-WDM systems. In case of wavelength-division-multiplexing (WDM) systems, this measurement should also take into account possible delay due to dispersion-compensating fibre (DCF).

NOTE 2 – In the case of WDM systems, the asymmetry due to the use of different wavelengths in the two directions should also be taken into account. Indeed, the use of different wavelengths on the two fibres, (or in a single fibre in the case of a transmission system using a single fibre), would result in different delays even if the fibres have the same length. Note also that a compensation related to the same aspect would be required if the wavelength used during the link asymmetry calibration process is different from the wavelength used by the traffic. Suitable methodologies in order to address this point are introduced in Appendix III.

The difference (d_f – d_r) can be used in the evaluation of the delay asymmetry to be used in the time recovering process. In particular the *delayAsymmetry* parameter as defined in section 7.4 of [IEEE 1588-2008] would be half of that difference.

NOTE 3 – If a T-BC is implemented in every node, the compensation can be triggered directly by the T-BC, which would know the difference (d_f – d_r). If this is not the case, some means have to be provided in order to make the difference (d_f – d_r) available at the points in the network where the precision time protocol (PTP) messages are processed. This is for further study.

I.7 Characteristics of the noise sources

Each of the sources of noise identified in previous clauses has different characteristics in terms of modelling and accumulation. As an example, the noise due to cascaded T-BC could be analysed according to the traditional approach followed in ITU-T for a chain of clocks.

The following clauses analyse the noise sources listed in the table above.

I.7.1 Reference time error

The packet master clock function of the T-GM receives a reference time to distribute. The error can be attributed to:

GNSS time error. Distribution schemes that use different GNSS systems (e.g., both GPS and future Galileo) might have an inherent time error due to the difference between the atomic clock ensembles that drive the systems.

GNSS implementation limitations. A GNSS receiver may produce a time signal that has an offset from another GNSS receiver that uses the same satellite system.

This noise source is applicable to PRTCs only.

The way the noise source, e_{ref}, is modelled is for further study.

I.7.2 PHY latency variation and asymmetry

This noise source is related to the hardware timestamping function, i.e., to the difference between the timestamp measurement point and the interface to the medium (e.g., 802.3bf defines the minimum and maximum transmit and receive values possible for each PHY supporting 802.3bf). For a proper implementation, this will typically be in the range of nanoseconds. The PHY latency asymmetry is defined as $(d_{tx}–d_{rx})/2$, where d_{tx} is the delay on the transmit path and d_{rx} is the delay on the receive path, as indicated in clause I.6 and Figure I.1.

This noise source is applicable to the packet master clock function (in a T-GM or a T-BC) and packet slave clock function (in a T-BC or in a T-TSC).

The way the noise source, e_{phy}, is modelled is for further study.

I.7.3 Timestamping granularity

The timestamping granularity depends on the sampling rate.

This noise source is applicable to the packet master and packet slave.

The way the noise source, e_{ts}, is modelled is for further study.

I.7.4 Local oscillator phase noise

The packet slave clock function uses the master timing data as reference to filter out its local reference phase noise, so as to produce a time error as small as possible. The better the local oscillator, the less noise it produces. Not all of the phase noise can be filtered out.

This noise source is applicable to the packet slave clock function (in a T-BC or in a T-TSC) when the frequency is recovered from the PTP messages (i.e., there is no physical layer frequency synchronization support).

The way the noise source, e_{φ}, is modelled is for further study.

I.7.5 Frequency reference phase error

The packet slave clock function (in a T-BC or in a T-TSC) may use an external frequency reference instead of its local oscillator to help with the recovery of time. The frequency reference will have much better timing characteristics than the local oscillator, but it will not be perfect.

This noise source is applicable to packet slave clock.

This noise source, e_{syncE}, is defined by the network limits in clause 9.2 of [ITU-T G.8261]. The way this noise source is modelled is for further study.

I.7.6 Time transients

Reference switches or short interruptions may cause time transients. Failure in the grandmaster or in a link may produce network rearrangement. During such period, time error can accumulate due to some form of holdover functionality.

This noise source is applicable to packet slave clock.

The way the noise source, $e_{transient}$, is modelled is for further study.

I.7.7 Link asymmetry

Packet timing protocols (such as the network time protocol (NTP) and the precision time protocol (PTP) measure the round-trip delay through a network, i.e., the delay from a server to a client and back (or vice versa). The one-way delay is then estimated using the assumption that the forward delay through a network is the same as the reverse delay. Any difference between the forward and reverse delay, (known as delay asymmetry), creates an error in the estimate of the client clock's offset from the server.

The use of full timing support (such as T-BC or T-TC in every node) can eliminate delay asymmetry due to packet delay variation (PDV), and different traffic load on the two traffic directions and asymmetry caused by packets taking different routes in each direction (in this case an end-to-end transparent clock however would not solve the issue). However, it is unable to correct delay asymmetry on point-to-point links between network elements. This asymmetry arises because the forward and reverse paths travel down different fibres or copper pairs in the same cable. These fibres or pairs may have different lengths and different electrical or optical characteristics which are sufficient to create delay differences.

Delay asymmetry created by fibre links can have several nanoseconds per metre of difference in each direction. When used over multiple fibre links, the magnitude of this error can become significant relative to the very tight tolerances required by some of the applications being considered.

The link asymmetry is defined as $(d_{ms}–d_{sm})/2$, where d_{ms} is the delay on the path from the master clock or responder to the slave clock or requestor, and d_{sm} is the delay on the path from the slave clock or requestor to the master clock or responder, as indicated in clause I.6 and Figure I.1.

This noise source is applicable to links.

The way the noise source, $e_{link\text{-}asym}$, is modelled is for further study.

I.7.8 Error in distributing time inside a node

This error is due to various internal delays when distributing a time reference from a centralized location in a node (e.g., system card) to other locations in a node (e.g., line card). This error might be attributed, for example, to the length of backplane traces, connectors, and various logic functions.

NOTE – These delays might be non-negligible and proper design and compensation should be performed.

This noise source is defined as $e_{intranode}$, and is for further study. This noise source is applicable to T-GM, T-BC and T-TSC.

Appendix II

Time and phase end application synchronization requirements

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

The following table summarizes the main requirements applicable at the output of the application (e.g., on the radio interface in the case of wireless application).

Table II.1 – Time and phase end-application requirements

Application/ Technology	Accuracy	Specification
CDMA2000	± 3 µs with respect to CDMA System Time (which is traceable and synchronous to UTC) ± 10 µs with respect to CDMA System Time for a period not less than 8 hours (when the external source of CDMA system time is disconnected)	[b-3GPP2 C.S0002] [b-3GPP2 C.S0010]
TD-SCDMA (NodeB TDD mode)	3 µs maximum deviation in frame start times between any pair of cells on the same frequency that have overlapping coverage areas	[b-3GPP TS 25.123] section 7.2
WCDMA-TDD (NodeB TDD mode)	In TDD mode, to support Intercell Synchronization and Handoff, a common timing reference among NodeB is required, and the relative phase difference of the synchronisation signals at the input port of any NodeB in the synchronized area shall not exceed 2.5 µs	[b-ETSI TS 125 402] sections 6.1.2 and 6.1.2.1
W-CDMA MBSFN	12.8 µs for MBMS over a single frequency network, where the transmission of NodeB is closely time synchronized to a common reference time	[b-3GPP TS 25.346] section 7.1A and 7.1B.2.1
LTE MBSFN	Values < ± 1 µs with respect to a common time reference (continuous timescale) have been mentioned	Under study
W-CDMA (Home NodeB TDD mode)	Microsecond level accuracy (no hard requirement listed)	[b-3GPP TR 25.866]
WiMAX	1) The downlink frames transmitted by the serving BS and the Neighbour BS shall be synchronized to a level of at least 1/8 cyclic prefix length (which is equal to 1.428 µs). At the base station, the transmitted radio frame shall be time-aligned with the 1pps timing pulse 2) The BS transmit reference timing shall be time-aligned with the 1pps pulse with an accuracy of ± 1 µs	[b-IEEE 802.16] WiMAX Forum Mobile System Profile Specification WMF-T23-001-R015v01 (2009)
LTE-TDD (Wide-Area Base station)	3 µs for small cell (< 3 km radius) 10 µs for large cell (> 3 km radius) maximum absolute deviation in frame start timing between any pair of cells on the same frequency that have overlapping coverage areas	[b-3GPP TS 36.133])

Table II.1 – Time and phase end-application requirements

Application/ Technology	Accuracy	Specification
LTE-TDD (home-area base station)	1) 3 µs for small cell (< 500m radius). For large cell (> 500 m radius), 1.33 + $T_{propagation}$ µs time difference between Base Stations, where $T_{propagation}$ is the propagation delay between the Home BS and the cell selected as the network listening synchronization source. In terms of the network listening synchronization source selection, the best accurate synchronization source to GNSS should be selected. If the Home BS obtains synchronization without using network listening, the small cell requirement applies. 2) The requirement is 3.475 µs but in many scenarios a 3 µs sync requirement can be adopted.	[b-3GPP TS 36.133] [b-3GPP TR 36.922]
LTE-TDD to CDMA 1xRTT and HRPD handovers	eNodeB shall be synchronized to GPS time. With external source of CDMA system time disconnected, the eNodeB shall maintain the timing accuracy within ± 10 µs with respect to CDMA system time for a period of not less than 8 hours	[b-TS 36.133]
LTE-advanced	Phase/Time requirements for the applications listed below are currently under study: • Carrier Aggregation • Coordinated Multipoint Transmission (aka Network-MIMO) • Relaying function	[b-TR 36.814]
IP network delay monitoring	The requirement depends on the level of quality that shall be monitored. As an example ± 100 µs with respect to a common time reference (e.g., UTC) may be required. ± 1 ms has also been mentioned	NOTE – There is no standard requirement yet. Requirements are operator dependent (depending on the application)
Billing and alarms	± 100 ms with respect to a common time reference (e.g., UTC)	
NOTE 1 – In the case of mobile applications, 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. NOTE 2 – The requirements are generally valid during normal conditions. The applicable requirements during failure conditions are for further study.		

Appendix III

Asymmetry compensation for use of different wavelengths

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

The compensation of asymmetry due to the use of different wavelengths is obtained by calculating the group delay applicable to wavelengths used in the forward and in the reverse direction.

Indicating with A the asymmetry, the following applies:

$$A = d_f - d_r = L * (n_r - n_f)/c,$$

Where L is the distance, c is the speed of light, d_f and d_r are the forward and reverse transmission delay, and n_r and n_f are the group refractive indexes applicable at the wavelength used in the forward and reverse direction respectively.

The evaluation of the refractive indexes can be done either using known chromatic dispersion data (e.g., from the optical fibre data-sheet) or, in the case that the dispersion in unknown, making a direct delay measurement at three different wavelengths (the refractive index for an arbitrary wavelength can then be derived by quadratic interpolation).

These data can then be used to derive the group delay of a generic wavelength. In particular, in the case of an ITU-T G.652 compliant fibre, the group delay at the applicable wavelengths can be calculated making use of the Sellmeier equations as described in [b-ITU-T G.652].

Bibliography

[b-ITU-T G.652] Recommendation ITU-T G.652 (2009), *Characteristics of a single-mode optical fibre and cable*.

[b-ETSI TS 125 402] ETSI TS 125 402 (2009), *Universal Mobile Telecommunications Systems (UMTS); Synchronization in UTRAN Stage 2*. <http://webapp.etsi.org/workprogram/Report_WorkItem.asp?WKI_ID=22972>

[b-IEEE 802.16] IEEE 802.16-2009, *IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems*.

[b-3GPP TR 25.836] 3GPP TR 25.836 (2001), *Node B synchronization for TDD.* <http://www.3gpp1.com/ftp/Specs/html-info/25836.htm>

[b-3GPP TR 25.866] 3GPP TR 25.866 (2009), *1.28 Mcps TDD Home NodeB (HNB) study item technical report*.

[b-3GPP TR 36.814] 3GPP TR 36.814 (2010), *Evolved Universal Terrestrial Radio Access (E-UTRA)*; *Further advancements for E-UTRA physical layer aspects*.

[b-3GPP TR 36.922] 3GPP TR 36.922 (2010), *Evolved Universal Terrestrial Radio Access (E-UTRA); TDD Home eNode B (HeNB) Radio Frequency (RF) requirements analysis*.

[b-3GPP TS 25.123] 3GPP TS 25.123 Release 9 (2009), *Requirements for support of radio resource management (TDD).*

[b-3GPP TS 25.346] 3GPP TS 25.346 (2009), *Introduction of the Multimedia Broadcast/Multicast Service (MBMS) in the Radio Access Network (RAN); Stage 2*.

[b-3GPP TS 36.133] 3GPP TS 36.133 (2011), *Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management*.

[b-3GPP2 C.S0010] 3GPP2 C.S0010-C v2.0 (2006), *Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Base Stations*. <http://www.3gpp2.org/Public_html/specs/C.S0010-C_v2.0_060315.pdf>

[b-3GPP2 C.S0002] 3GPP2 C.S0002-E v2.0 (2010), *Physical layer standard for cdma2000 Spread Spectrum Systems.* <http://www.3gpp2.org/Public_html/specs/C.S0002-E_v2.0_cdma2000_1x_PHY.pdf>

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