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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

Timing and synchronization aspects in packet networks

Recommendation ITU-T G.8261/Y.1361

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Recommendation ITU-T G.8261/Y.1361

Timing and synchronization aspects in packet networks

Summary

Recommendation ITU-T G.8261/Y.1361 defines frequency synchronization aspects in packet networks. It specifies the maximum network limits of jitter and wander that shall not be exceeded. It specifies the minimum equipment tolerance to jitter and wander that shall be provided at the boundary of these packet networks at TDM and synchronization interfaces. It also outlines the minimum requirements for the synchronization function of network elements.

The requirements for the jitter and wander 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

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FOREWORD

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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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Recommendation ITU-T G.8261/Y.1361

Timing and synchronization aspects in packet networks

1 Scope

This Recommendation defines frequency synchronization aspects in packet networks. It specifies the maximum network limits of jitter and wander that shall not be exceeded. It specifies the minimum equipment tolerance to jitter and wander that shall be provided at the boundary of these packet networks at TDM and synchronization interfaces. It also outlines the minimum requirements for the synchronization function of network elements.

In particular, two main issues are addressed in this Recommendation: the distribution of a synchronization network clock signal over a packet network (PNT domain), and the distribution of a service clock signal over a packet network (CES domain).

NOTE – The application of the transport of SDH signals over packet networks is only partly covered and some aspects are for further study.

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

- Ethernet ([IEEE 802.3], [IEEE 802.1DTM], [IEEE 802.1QTM] and [IEEE 802.1QayTM])
- MPLS [IETF RFC 3031] and [ITU-T G.8110]
- IP [IETF RFC 791] and [IETF RFC 2460]

The physical layer that is relevant to this Recommendation is the Ethernet media types as defined in [IEEE 802.3]. Other physical layers can be relevant and may be addressed in a future version of this Recommendation.

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.691] | Recommendation ITU-T G.691 (2006), <i>Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers.</i> |
| [ITU-T G.702] | Recommendation ITU-T G.702 (1988), <i>Digital hierarchy bit rates.</i> |
| [ITU-T G.703] | Recommendation ITU-T G.703 (2001), <i>Physical/electrical characteristics of hierarchical digital interfaces.</i> |
| [ITU-T G.705] | Recommendation ITU-T G.705 (2000), <i>Characteristics of plesiochronous digital hierarchy (PDH) equipment functional blocks.</i> |
| [ITU-T G.781] | Recommendation ITU-T G.781 (2008), <i>Synchronization layer functions.</i> |
| [ITU-T G.803] | Recommendation ITU-T G.803 (2000), <i>Architecture of transport networks based on the synchronous digital hierarchy (SDH).</i> |
| [ITU-T G.811] | Recommendation ITU-T G.811 (1997), <i>Timing characteristics of primary reference clocks.</i> |



- [ITU-T G.812] Recommendation ITU-T G.812 (2004), *Timing requirements of slave clocks suitable for use as node clocks in synchronization networks.*
- [ITU-T G.813] Recommendation ITU-T G.813 (2003), *Timing characteristics of SDH equipment slave clocks (SEC).*
- [ITU-T G.822] Recommendation ITU-T G.822 (1988), *Controlled slip rate objectives on an international digital connection.*
- [ITU-T G.823] Recommendation ITU-T G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy.*
- [ITU-T G.824] Recommendation ITU-T G.824 (2000), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy.*
- [ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH).*
- [ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.*
- [ITU-T G.959.1] Recommendation ITU-T G.959.1 (2008), *Optical transport network physical layer interfaces.*
- [ITU-T G.8010] Recommendation ITU-T G.8010/Y.1306 (2004), *Architecture of Ethernet layer networks.*
- [ITU-T G.8110] Recommendation ITU-T G.8110/Y.1370 (2005), *MPLS layer network architecture.*
- [ITU-T G.8110.1] Recommendation ITU-T G.8110.1/Y.1370.1 (2006), *Architecture of Transport MPLS (T-MPLS) layer network.*
- [ITU-T G.8260] Recommendation ITU-T G.8260 (2010), *Definitions and terminology for synchronization in packet networks.*
- [ITU-T G.8261.1] Recommendation ITU-T G.8261.1/Y.1361.1 (2012), *Packet delay variation network limits applicable to packet-based methods (Frequency synchronization).*
- [ITU-T G.8262] Recommendation ITU-T G.8262/Y.1362 (2010), *Timing characteristics of synchronous Ethernet equipment slave clock.*
- [ITU-T G.8263] Recommendation ITU-T G.8263/Y.1363 (2012), *Timing characteristics of packet-based equipment clocks.*
- [ITU-T G.8264] Recommendation ITU-T G.8264/Y.1364 (2008), *Timing distribution through packet networks.*
- [ITU-T G.8265] Recommendation ITU-T G.8265/Y.1365 (2010), *Architecture and requirements for packet-based frequency delivery.*
- [ITU-T G.8265.1] Recommendation ITU-T G.8265.1/Y.1365.1 (2010), *Precision time protocol telecom profile for frequency synchronization.*
- [ITU-T G.8271] Recommendation ITU-T G.8271/Y.1366 (2012), *Time and phase synchronization aspects of packet networks.*
- [ITU-T O.171] Recommendation ITU-T O.171 (1997), *Timing jitter and wander measuring equipment for digital systems which are based on the plesiochronous digital hierarchy (PDH).*

- [ITU-T O.172] Recommendation ITU-T O.172 (2005), *Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)*.
- [ITU-T Y.1411] Recommendation ITU-T Y.1411 (2003), *ATM-MPLS network interworking – Cell mode user plane interworking*.
- [ITU-T Y.1540] Recommendation ITU-T Y.1540 (2002), *Internet protocol data communication service – IP packet transfer and availability performance parameters*.
- [ITU-T Y.1561] Recommendation ITU-T Y.1561 (2004), *Performance and availability parameters for MPLS networks*.
- [ITU-T Y.1731] Recommendation ITU-T Y.1731 (2006), *OAM functions and mechanisms for Ethernet based networks*.
- [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) Bridges*.
<<http://standards.ieee.org/getieee802/download/802.1D-2004.pdf>>
- [IEEE 802.1Q] IEEE 802.1Q-2011, *IEEE Standard for local and metropolitan area networks: Virtual bridged local area networks*.
<<http://standards.ieee.org/getieee802/download/802.1Q-2011.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>>
- [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

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

- 3.1.1 adaptive clock recovery:** See [ITU-T G.8260].
- 3.1.2 asynchronous interface:** See [ITU-T G.823].
- 3.1.3 interworking function (IWF):** See [ITU-T Y.1411]. More details and examples are shown in Annex B and Appendix IX.
- 3.1.4 packet-based method:** See [ITU-T G.8260].
- 3.1.5 packet-based method with timing support from the network:** See [ITU-T G.8260].
- 3.1.6 packet-based method without timing support from the network:** See [ITU-T G.8260].
- 3.1.7 packet network timing function (PNT-F):** See [ITU-T G.8260].
- 3.1.8 synchronous interface:** See [ITU-T G.823].
- 3.1.9 traffic interface:** See [ITU-T G.823].

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 CES IWF: The circuit emulation services (CES) interworking function (IWF) is the set of functions within the IWF that supports the service clock domain (see Figure B.3). This includes the function to recover the service clock timing.

3.2.2 circuit emulation services (CES) island: Segment of a network, based on packet-switched technologies, that emulates either the characteristics of a circuit-switched network or of a PDH/SDH transport network, in order to carry CBR services (e.g., E1).

3.2.3 frequency source traceability: Frequency source traceability is a relationship where the frequency of all clocks in a system is referenced back to a single physical clock. Under normal operating conditions, all clocks will have the same average frequency in a source-traceable system. Thus, the phase error or maximum time interval error (MTIE) between all clocks in such a system is bounded.

NOTE – A different case is when the clocks have frequency traceability towards accurate master clocks (not necessarily the same pieces of equipment). This is connected to the concept of plesiochronous as defined in [b-ITU-T G.810]. An example is when the clocks have the "PRC traceability" (i.e., traceability to [ITU-T G.811] clocks) in a synchronization network based on the distributed PRC architecture.

3.2.4 network clock: The clock generating the network clock signal.

3.2.5 network clock domain: Set of functions dedicated to support the synchronization network (network clock).

3.2.6 network clock signal: A reference timing signal that is used as a reference to allow mapping and demapping of a service clock at ingress and egress points of the network respectively. In some applications, the signal could be asynchronous and generated by free running clocks with low requirements in terms of frequency accuracy (e.g., in the Ethernet network, the physical layer can operate up to ± 100 ppm). In other applications, an accurate reference timing signal is needed. In this case, the signal is typically traceable to a PRC under normal conditions, and the distribution of this signal across the network is accomplished by a synchronization network.

NOTE – For the purpose of this Recommendation, it is assumed that a properly high accurate signal is always involved. Due to that, the network clock signal definition can be considered to coincide with the definition of synchronization network clock signal, and the two terms are used interchangeably throughout this Recommendation.

3.2.7 network-synchronous operation: Synchronization of the physical layer (usually by a timing distribution of a timing signal traceable to a primary reference clock (PRC), see [ITU-T G.811]).

3.2.8 service clock: The clock generating the service clock signal.

3.2.9 service clock domain: Set of functions dedicated to support the CES timing function (service clock).

3.2.10 service clock signal: The timing information that is associated with a specific service supported by a network. For instance, in case of E1 TDM service, the timing shall be 2048 kbit/s ± 50 ppm.

3.2.11 synchronization network clock: The equipment that provides the timing signal in the synchronization network.

3.2.12 synchronization network clock signal: The reference timing signal distributed by the synchronization network. This signal is traceable to an accurate master (e.g., PRC).

3.2.13 time division multiplex (TDM): A term that conventionally refers to the isochronous bitstreams used in telephony networks; in particular, those belonging to plesiochronous digital hierarchy (PDH) as described in [ITU-T G.705]. The bit rates traditionally used in various regions of the world are detailed in [ITU-T G.702]. Examples of the signals covered by the TDM definition are those belonging to PDH and SDH hierarchies.

3.2.14 stabilization period: The period beginning at the point in time when a validated timing source has been selected by the IWF and ending when the output timing characteristics are within the output jitter and wander requirements.

3.2.15 wander budget (of a network island): Wander generated at the output of a network island when an ideal reference timing signal is the input at the first network element of this network island.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3GPP	Third Generation Partnership Project
ATM	Asynchronous Transfer Mode
BS	Base Station
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CE	Customer Equipment
CES	Circuit Emulation Service
DUT	Device Under Test
EEC	synchronous Ethernet Equipment Clock
ESMC	Ethernet Synchronization Messaging Channel
FDD	Frequency Division Duplex
FE	Fast Ethernet
GE	Gigabit Ethernet
GPS	Global Positioning System
GSM	Global System for Mobile communications
IP	Internet Protocol
IP DSLAM	IP Digital Subscriber Line Access Multiplexer
IWF	Interworking Function
MAC	Medium Access Control
M-CMTS	Modular Cable Modem Termination System
MPEG	Moving Picture Experts Group
MRTIE	Maximum Relative Time Interval Error
MSAN	MultiService Access Node
MTIE	Maximum Time Interval Error
NTP	Network Time Protocol
OLT	Optical Line Termination

OTN	Optical Transport Network
PDH	Plesiochronous Digital Hierarchy
PDV	Packet Delay Variation
PEC	Packet-based Equipment Clock
PHY	PHYsical (layer)
PNT	Packet Network Timing
PNT-F	PNT-Function
PRC	Primary Reference Clock
PSC-A	Packet-based Service Clock-Adaptive
PSC-D	Packet-based Service Clock-Differential
PSTN	Public Switched Telephone Network
PTP	Precision Time Protocol
QL	Quality Level
SASE	Stand Alone Synchronization Equipment
SDH	Synchronous Digital Hierarchy
SEC	SDH Equipment Clock
SLA	Service Level Agreement
SNTP	Simple Network Time Protocol
SRTS	Synchronous Residual Time Stamp
SSM	Synchronization Status Message
SSU	Synchronization Supply Unit
STM	Synchronous Transfer Mode
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDEV	Time DEViation
TDM	Time Division Multiplex
TDM PW	TDM PseudoWire
ToD	Time of Day
UI	Unit Interval
UTC	Coordinated Universal Time
WCDMA	Wideband Code Division Multiple Access

5 Conventions

The terms "packets" and "frames" are used interchangeably throughout this Recommendation.

Within this Recommendation, the term "Ethernet" refers to an interface as defined in [IEEE 802.3] and that does not comply with the additional timing requirements of synchronous Ethernet as specified in this Recommendation, in [ITU-T G.8262] and in [ITU-T G.8264].

6 General

Packet switching was originally introduced to handle asynchronous data.

However, for new applications, such as the transport of time division multiplex (TDM) service and the distribution of synchronization over packet networks, the strict synchronization requirements of those applications must be considered.

The ongoing evolution in telecommunications increases the likelihood of hybrid packet/circuit environments for voice and voiceband data services. These environments combine packet technologies (e.g., asynchronous transfer mode (ATM), IP, Ethernet) with traditional TDM systems. Under these conditions, it is critical to ensure that an acceptable level of quality is maintained (e.g., limited slip rate).

Synchronization in TDM networks is well understood and implemented. Typically, a TDM circuit service provider will maintain a timing distribution network, providing synchronization traceable to a primary reference clock (i.e., clock compliance with [ITU-T G.811]).

The timing and synchronization aspects addressed in this Recommendation are initially concerned with networks with physical layer based on Ethernet media types as defined in [IEEE 802.3] (see Scope, clause 1).

The functional architecture for Ethernet networks is defined in [ITU-T G.8010].

In the context of this Recommendation, the highest layers (e.g., layer 7 in the Open Systems Interconnection (OSI) model) refer to applications transported over the packet networks. Real-time applications have relatively tight timing requirements concerning delay and delay variation. Some applications might resolve their timing issues within higher layers (e.g., MPEG-2); other applications rely on the timing support provided by one or more of the lower layers (e.g., physical layer).

This Recommendation aims at describing different methods to obtain the synchronization-related requirements. Both circuit emulation services (CES) and packet network timing (PNT) domains are considered, and different requirements are described.

Additionally, the requirements for interfaces and equipments that are part of the Ethernet and synchronous Ethernet network are described. It also recommends when to apply different types of synchronization methods.

Some considerations on applicable synchronization requirements in a packet-based network are summarized in the following clauses.

This Recommendation primarily deals with CES in public network environments. In some private network applications involving circuit emulation, it may be sufficient to distribute a non-primary reference clock (PRC) quality level common clock towards CES interworking function (IWF) nodes. However, the use of synchronization timing below PRC quality level could result in interworking difficulties between different network domains, such as interconnection involving multiple public networks providers.

The use of a non-PRC quality level common clock is for further study.

6.1 Packet network synchronization requirements

The nodes involved in packet oriented transmission technology (e.g., ATM network nodes) do not require any synchronization for the implementation of the packet switching function. In fact, at any entrance point of a packet switch, an individual device shall provide packet timing adaptation (for instance, cell timing adaptation in case of ATM switch) of the incoming signal to the internal timing. For instance, in the case of ATM networks, the principle to cater for frequency differences is to use idle cell stuffing. Therefore, transmission links, in principle, need not be synchronized with each other.

However, as the packet network evolves to integrate TDM-based applications, i.e., when transporting a constant bit rate (CBR) stream over a packet network and when interworking with public switched telephone network (PSTN) networks, the packet network shall provide correct timing at the traffic interfaces.

This means that the requirements on synchronization functions in packet networks, especially on the boundary of the packet networks, are dependent on the services carried over the network. For TDM based services, the IWF may require network-synchronous operation in order to provide acceptable performance.

6.2 TDM timing requirements

The transport of TDM signals through packet networks requires that the signals at the output of the packet network comply with TDM timing requirements. This is crucial to enable interworking with TDM equipment.

These requirements are independent of the type of information (voice or data) transported by the TDM signal.

The adaptation of TDM signals into the packet network is called circuit emulation services (CESs).

The timing requirements that are applicable are: jitter and wander limits at traffic and/or synchronization interfaces, long-term frequency accuracy (which can influence the slip performance), and total delay (which is critical for real-time services, for instance voice service).

6.2.1 PDH timing requirements

The plesiochronous digital hierarchy (PDH) timing requirements for traffic interfaces are mainly related to jitter, wander and slip performance.

At the input of the network element at the boundary of a packet network, jitter and wander tolerance requirements apply. At the output of the network element at the egress of the packet network, jitter and wander generation requirements apply.

These values are specified in [ITU-T G.823] for a network based on 2048 kbit/s hierarchy and [ITU-T G.824] for a network based on 1544 kbit/s hierarchy.

In addition, [ITU-T G.822] specifies the applicable slip rate objectives. This is the case when the clock of the equipment that generates the TDM signal and the clock used in the equipment recovering the TDM signal from the packets are different and the slip buffer is needed in the application.

6.2.2 Synchronization interfaces requirements

In the case where the PDH signals are defined as synchronization interfaces, the synchronization requirements are more stringent than those for the 2048 kbit/s and 1544 kbit/s traffic interfaces. The synchronization interface requirements for PDH interfaces are also defined in [ITU-T G.823] and [ITU-T G.824].

6.2.3 SDH timing requirements

Any synchronous transfer mode (STM)-N signal must be compliant with [ITU-T G.825]. The relevant requirements refer to the jitter and wander tolerance applicable at the input of the network element at the boundary of a packet network that receives the STM-N data, and jitter and wander generation applicable at the output of the network element generating STM-N traffic at the other end of the packet network.

In the case of STM-N signals, there are no distinctions between traffic and synchronization interfaces as all STM-N signals are defined as synchronization interfaces.

6.3 Synchronization network engineering in packet networks

The driving force for much of this work is to provide for the synchronization needs of the application or, in general, the need of certain technologies (such as base stations in global system for mobile communications (GSM) and wideband code division multiple access (WCDMA) networks). In order to achieve such a goal, operators have to distribute a reference timing signal of suitable quality to the network elements processing the application.

One approach is to follow a distributed PRC strategy (e.g., by means of global positioning system (GPS) technologies). An alternative approach is based on a master-slave strategy. The engineering rules for designing the synchronization network in these cases are well understood and documented (e.g., see [ITU-T G.803]) when the underlying transport of the packets (e.g., Ethernet frames) runs over the existing synchronous technologies (PDH or synchronous digital hierarchy (SDH) networks). On the other hand, when the underlying transport is based on non-synchronous technologies (i.e., Ethernet) alternative approaches shall be considered. This is further analysed in clause 7.

6.4 Timing requirements at edge versus timing requirements in core networks

Different performances can be requested in case the packet network is part of an access network or is the underlying layer of the core network.

The distribution of a synchronization reference over a portion of a core network may be requested to comply with strict jitter and wander requirements (i.e., [ITU-T G.823], [ITU-T G.824] for synchronization interfaces and [ITU-T G.825]).

On the other hand, in an access network, requirements may be relaxed to allow a distribution of a timing reference signal with performance sufficient (e.g., lower than PRC quality level) to support the timing requirements of the end node (for instance, a base station, or an ITU-T V.90 modem). More information is provided in Appendix IV.

6.5 PNT domain and CES domain

This Recommendation addresses two main different issues:

- 1) how to carry a synchronization network clock signal over a packet network:
 - this issue is related to the PNT domain, and refers to the network clock (see definitions).
 - guidance regarding this issue is provided in clause 7.
- 2) how to carry a service clock signal:
 - this issue is related to the CES domain, and refers to the service clock (see definitions).
 - guidance regarding this issue is provided in clause 8.

Additional information regarding PNT and CES domains is provided in Annex B.

7 Reference timing signal distribution over packet networks (PNT domain)

In order to fulfil the applicable synchronization requirements, it should be possible to distribute a reference timing signal with proper phase stability and frequency accuracy characteristics.

Two main classes of methods are identified in this Recommendation:

- 1) plesiochronous and network synchronous methods (i.e., reference timing signal distributed over the synchronous physical layer).
- 2) packet-based methods.

7.1 Plesiochronous and network synchronous methods

The first class of methods refers to the PRC distributed method (for instance, based on GPS), or the master-slave method using a synchronous physical layer (e.g., STM-N), see Figure 1. These methods are widely implemented to synchronize the TDM networks.

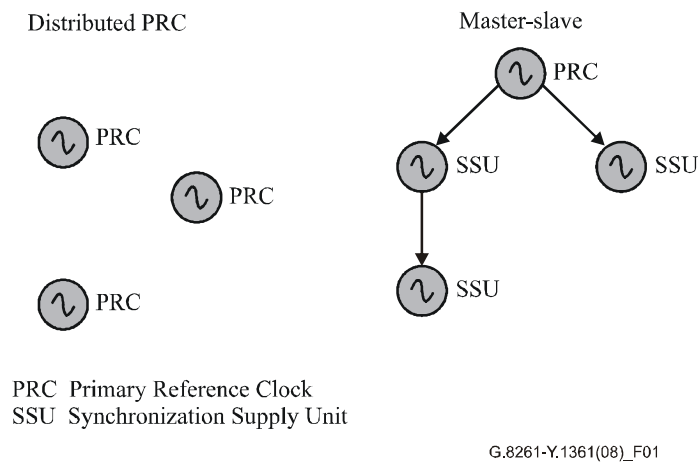


Figure 1 – Distributed PRC and master-slave methods

Ethernet networks are free-running (± 100 ppm). However, in case of synchronous Ethernet, it is possible to design a master-slave synchronization architecture at the physical layer. In this case, the physical layer can be used to provide reference timing signal distribution over packet networks, from backbone level to access level. This method can also be used to provide timing recovery at the IWFs for CBR services transported over packet networks (network synchronous operations). It could also be used to provide a reference timing signal down to edge access equipment in a pure Ethernet network supporting synchronous Ethernet.

Clause 7.1.1 details a high-level method of achieving a synchronous Ethernet network.

7.1.1 Synchronous Ethernet networks

The general concept of delivering a physical layer clock from the Ethernet switch over the synchronous Ethernet is given in Figure 2.

A reference timing signal traceable to a PRC is injected into the Ethernet switch using an external clock port. This signal is extracted and processed via a synchronization function before injecting timing onto the Ethernet bitstream. The synchronization function provides filtering and may require holdover. The clock supporting synchronous Ethernet networks is called synchronous Ethernet equipment clock (EEC), see [ITU-T G.8262].

As shown in the figure, there may be a number of Ethernet switches involved in the distribution of the reference timing signal. In such cases, the synchronization function within these Ethernet switches must be able to recover synchronization "line timing" from the incoming bitstream.

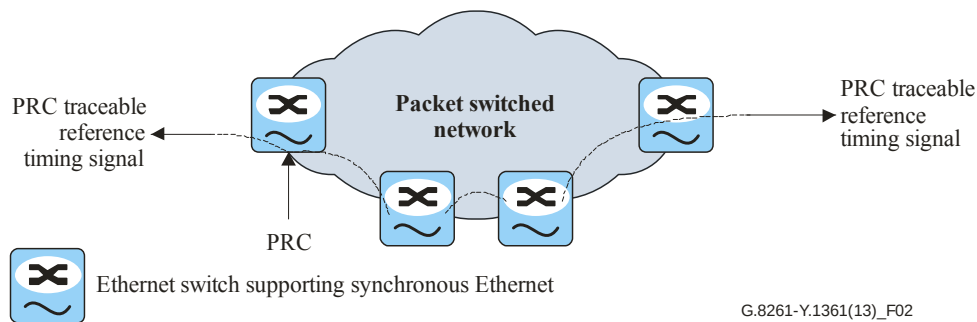


Figure 2 – Example of master-slave synchronization network over synchronous Ethernet

As part of the architecture, a distinction should be made between the network clock and the service clock as described below.

The term synchronous Ethernet applies to the network clock that controls the bit rate leaving the Ethernet switch. This clock shall comply with [ITU-T G.8262].

Within existing Ethernet technology, the service is effectively asynchronous. In synchronous Ethernet, existing Ethernet services will continue to be mapped into and out of the Ethernet physical layer at the appropriate rates as generated by the service clocks.

A proposed architecture for the synchronization networks based on synchronous Ethernet is described in Annex A.

NOTE – The synchronous Ethernet equipments have to comply with [ITU-T G.781] that specifies the synchronization layer, and [ITU-T G.8264] that specifies the synchronization status message (SSM) for synchronous Ethernet.

7.2 Packet-based methods

The second class of methods relies on timing information carried by the packets. In this case, the timing could be carried by dedicated time stamp messages as shown in Figure 3. In case the physical layer is not synchronous, this is the only alternative to a PRC distributed approach. The principles underlying such methods are outlined in Appendix XII.

The time stamp can be based on several protocols. Examples of protocols are network time protocol (NTP) and precision time protocol (PTP) (see clause XII.4).

The PTP protocol uses time stamps for synchronizing clocks in the network in a master-slave hierarchy. It can be used to distribute frequency and/or time of day (ToD) information. PTP was originally introduced for Industrial Automation and Test and Measurement Industries; however, a new version (see clause XII.4) has included several updates to allow it to be used for Telecom.

NTP and simple network time protocol (SNTP) are protocols traditionally used to distribute time of day information. The same packets may be used to distribute frequency information as well.

Packet-based methods are adaptive in nature, since they do not require the support of a network-wide synchronization reference. Therefore, performance is impacted by packet delay variation in the network (see clause 10). In order to minimize the impact from the packet network using either PTP or NTP packets, specific algorithms may need to be implemented at the client side, depending on the required accuracy (see Appendices III and IV).

Additional requirements on the intermediate nodes in the network can be considered to enhance the performance of these methods. It should be noted that, especially in cases where legacy equipment is used, this may not always be feasible.

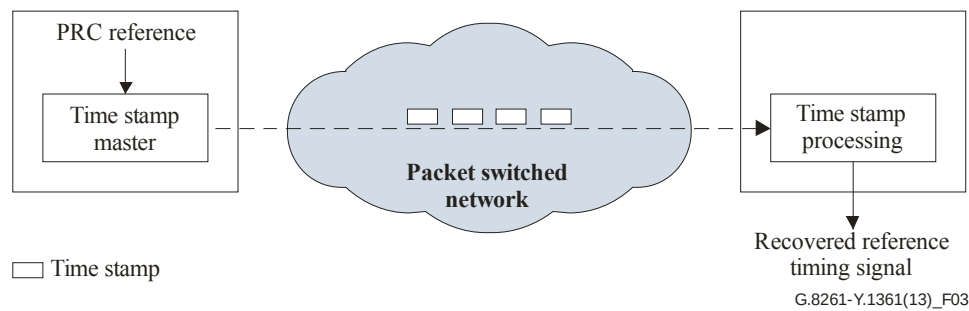


Figure 3 – Example of packet-based methods with timing distribution of the reference timing signal via time stamps

NOTE – For further details on packet-based methods and related requirements refer to [ITU-T G.8261.1], [ITU-T G.8263], [ITU-T G.8265] and [ITU-T G.8265.1]. Additional information and related Recommendations on packet-based methods are provided in clause 12.2.2.

The clock supporting packet-based methods is called packet-based equipment clock (PEC), (see Annex B).

8 Timing recovery for constant bit rate services transported over packet networks (CES domain)

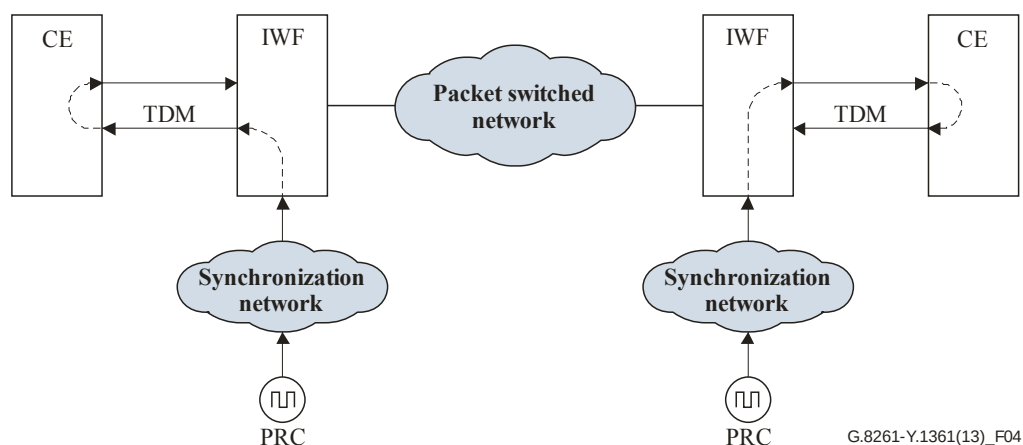
CBR services (e.g., circuit emulated TDM signal) require that the timing of the signal is similar on both ends of the packet network (CES domain) and is handled by the IWF responsible for delivering the constant bit rate stream. The notion of service clock preservation is that the incoming service clock frequency be replicated as the outgoing service clock frequency when considered in terms of a long-term average. It does not imply that wander on the incoming TDM signal be replicated on the outgoing TDM signal.

The four operating methods identified within this Recommendation are described in the following clauses:

- 1) network synchronous operation
- 2) differential methods
- 3) adaptive methods
- 4) reference clock available at the TDM end systems.

8.1 Network synchronous operation

This method refers to the fully network-synchronous operation by using a PRC traceable network derived clock or a local PRC (e.g., GPS) as the service clock (see Figure 4). This implies the availability of a PRC reference. It should be highlighted that this method does not preserve the service timing.



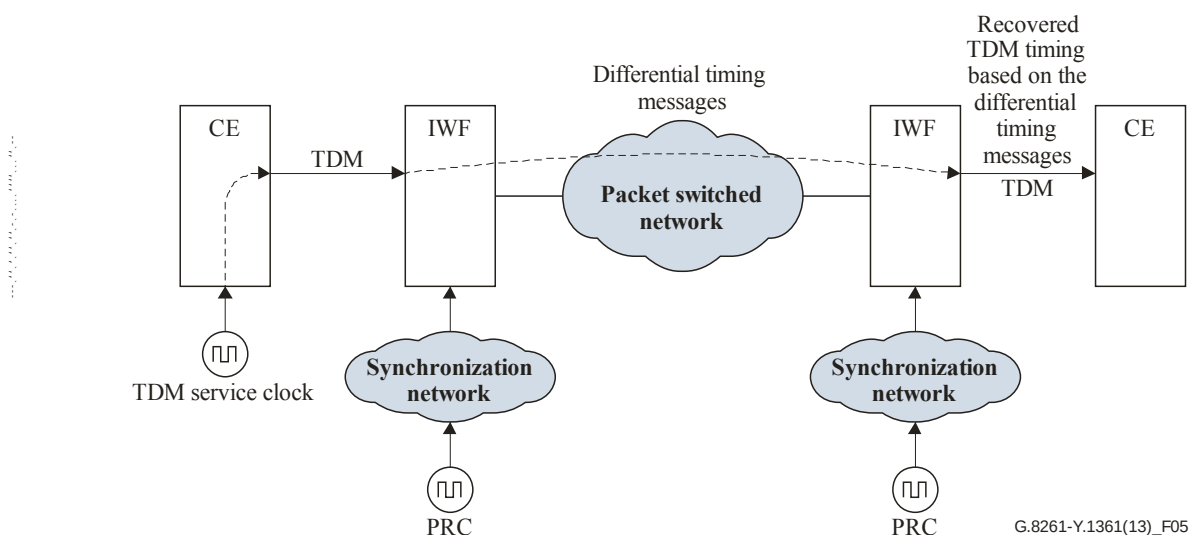
The two PRCs may also originate from the same source.

Figure 4 – Example of network synchronous operation

NOTE – The reference timing signal at the input to the IWF shall comply with synchronization interfaces as defined in [ITU-T G.823] and [ITU-T G.824].

8.2 Differential methods

According to the differential methods, the difference between the service clock and the reference clock is encoded and transmitted across the packet network (see Figure 5). The service clock is recovered on the far end of the packet network making use of a common reference clock. The synchronous residual time stamp (SRTS) method [b-ITU-T I.363.1] is an example of this family of methods. It should be highlighted that this method can preserve the service timing.



The two PRCs may also originate from the same source.

Figure 5 – Example of timing recovery operation based on differential methods

NOTE 1 – Differential methods may work with IWF reference clocks that are not PRC traceable. The use of non-PRC traceable clocks is application-dependent and is not within the scope of this Recommendation.

NOTE 2 – The reference timing signal at the input of the IWF shall comply with synchronization interfaces as defined in [ITU-T G.823] and [ITU-T G.824].

8.3 Adaptive methods

In the adaptive method, the timing can be recovered based on the inter-arrival time of the packets or on the fill level of the jitter buffer. It should be highlighted that this method preserves the service timing (see Figure 6).

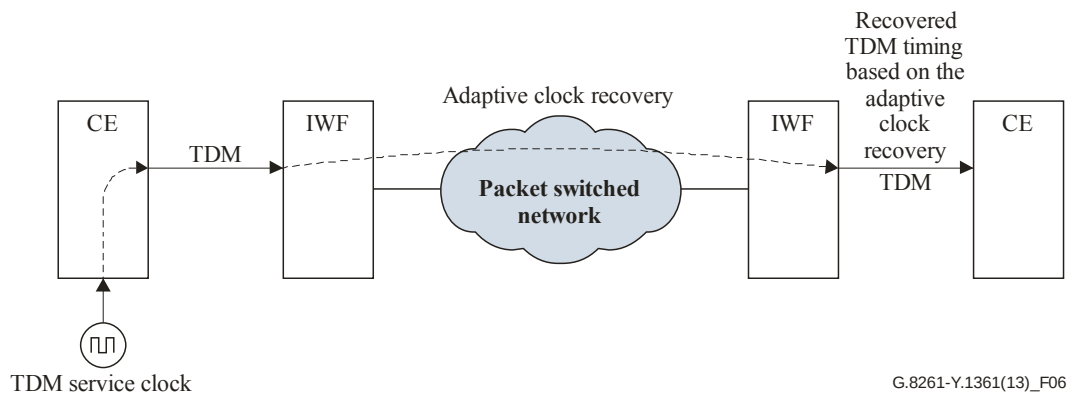
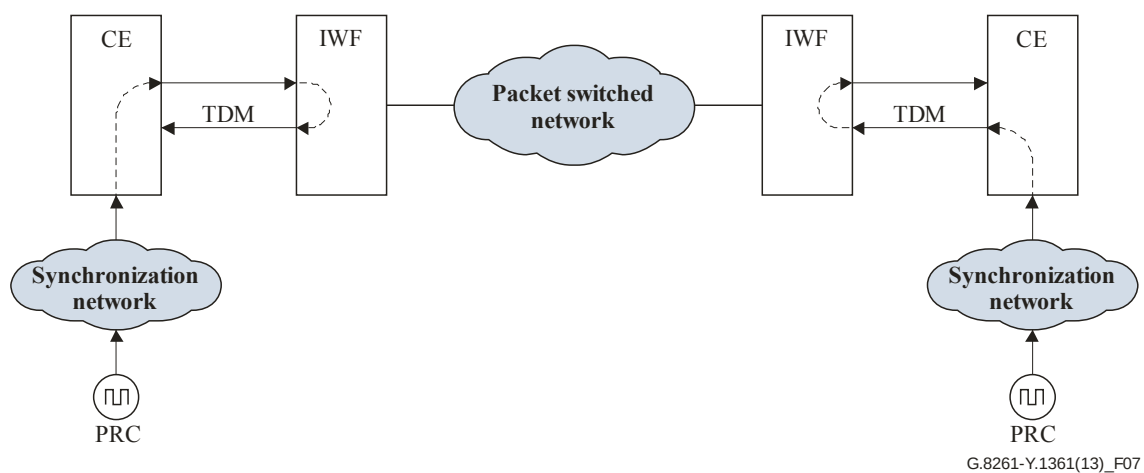


Figure 6 – Example of adaptive method

8.4 Reference clock available at the TDM end systems

When a reference clock is available at each TDM end system, this is a trivial case, since both the end systems have direct access to a timing reference, and will retime the signal leaving the IWF. Therefore, there is no need to recover the timing.

The use of loop timing in the IWF on the TDM interface is an example of the implementation of this method (see Figure 7). An example, of when this scenario might apply, is when two PSTN domains are connected via a packet network. In this case, both the transmitter and receiver are digital switches where there is a need to control slips.



The two PRCs may also originate from the same source.

Figure 7 – Example of PRC reference timing signal available at the TDM end systems

9 Network limits

9.1 CES network limits

The network limits on the TDM links at the output of the CES IWF (output of the Reference selector in the CES IWF in Figure B.4) are defined in this clause.

The jitter and wander network limits currently specified in the relevant ITU-T Recommendations (i.e., [ITU-T G.823] and [ITU-T G.824]) have to be fulfilled in all the scenarios that are relevant for this Recommendation.

This clause describes three different deployment scenarios for a CES segment or island. The jitter and wander limits for TDM traffic interfaces (excluding STM-N signals) carried over the CES segment in each of these scenarios are defined in this clause.

The network limits, applicable to synchronization interfaces (as specified in [ITU-T G.823] and in clause 6 of [ITU-T G.824]) and to STM-N signals carried over packet networks, are for further study.

It should be noted that in some cases, signals with quality, according to clause 5 of [ITU-T G.823] and clause 5 of [ITU-T G.824] (traffic interfaces), when traceable to a PRC, can be used as reference timing signals towards an end equipment able to tolerate these signals and to correctly operate (model for Deployment Case 2 is an example of this scenario).

NOTE – The network limits provided by this clause shall be valid under normal conditions (e.g., when failure conditions or maintenance actions are not present). It is out of the scope of this Recommendation to specify the proportion of time during which these limits apply.

9.1.1 Network model underlying the network limits

For the transport of PDH signals, the models in Figure A.1 of [ITU-T G.823] and in Figure A.1 of [ITU-T G.824] are the starting point to consider the insertion of a CES segment. The wander budget allocation for the CES segment must be only a portion of the entire wander budget as specified in [ITU-T G.823] or [ITU-T G.824], since the total wander budget has to be shared with the rest of the network.

Depending on where the CES segment is located, different wander requirements may apply. Several models of CES deployment have been identified; the models are defined in clauses 9.1.1.1, 9.1.1.2 and 9.1.1.3.

NOTE 1 – The figures in this clause do not show the details on how the timing is recovered by the IWF or how the timing is distributed in the packet network. For further details, refer to clauses 7 and 8.

NOTE 2 – Only one CES island is presented in these models, since it aims at allocating wander budget only for the CES technology segment. There might be several CES systems as long as their accumulated wander generation is within the budget allocated for CES.

The wander accumulation through multiple islands is for further study.

9.1.1.1 Deployment Case 1

When the CES segment is located at an island between the two switches of the [ITU-T G.823] reference model, the wander budget is calculated based on the model in Figure 8. The model is based on Figure A.1 of [ITU-T G.823] and Figure A.1 of [ITU-T G.824] where one of the SDH islands is replaced by the CES network.

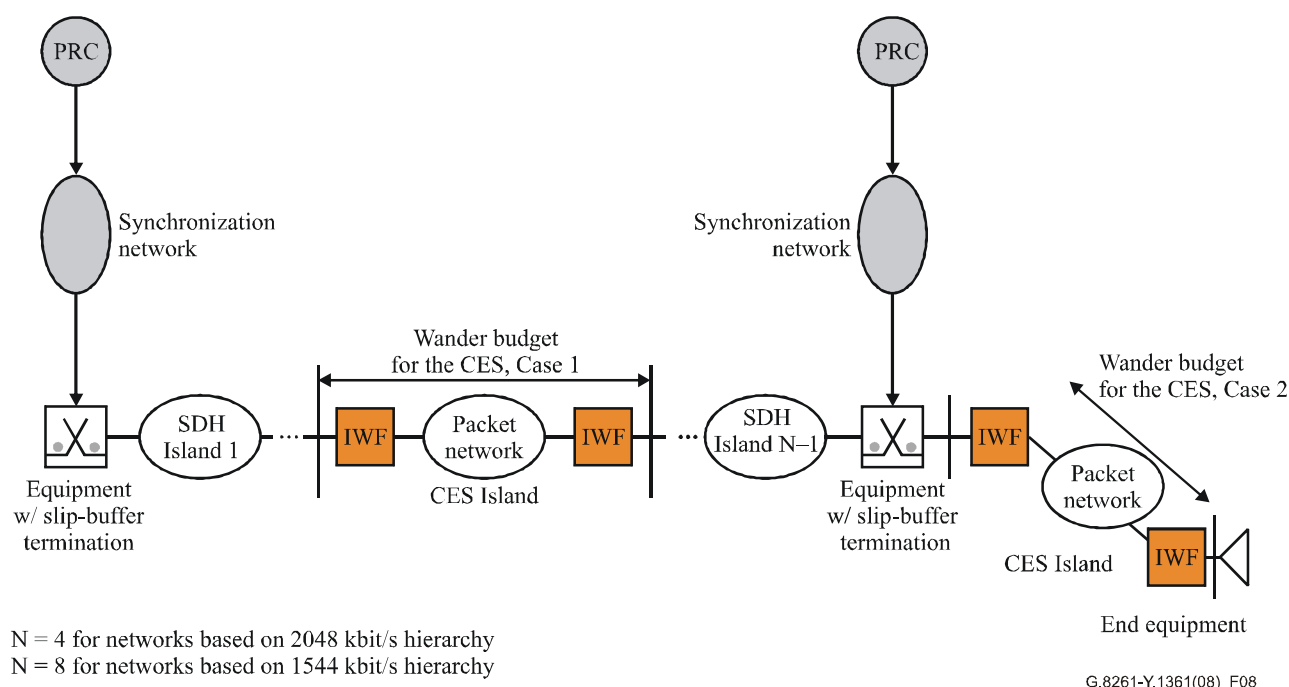


Figure 8 – Network models for traffic and clock wander accumulation, Deployment Case 1 and Case 2

The wander budget, expressed in maximum relative time interval error (MRTIE), for 2048 kbit/s signal is defined in Table 1. The resultant overall specification is illustrated in Figure 9.

Table 1 – Deployment Case 1: 2048 kbit/s interface wander budget

Observation Interval τ (s)	MRTIE requirement (μ s)
$0.05 < \tau \leq 0.2$	10.75τ
$0.2 < \tau \leq 32$	$9 \times 0.24 = 2.15$
$32 < \tau \leq 64$	0.067τ
$64 < \tau \leq 1000$	$18 \times 0.24 = 4.3$
Note that for the asynchronous configuration, the maximum observation interval to be considered is 80 s. The specification between 80 s and 1000 s for the asynchronous interfaces is for further study.	

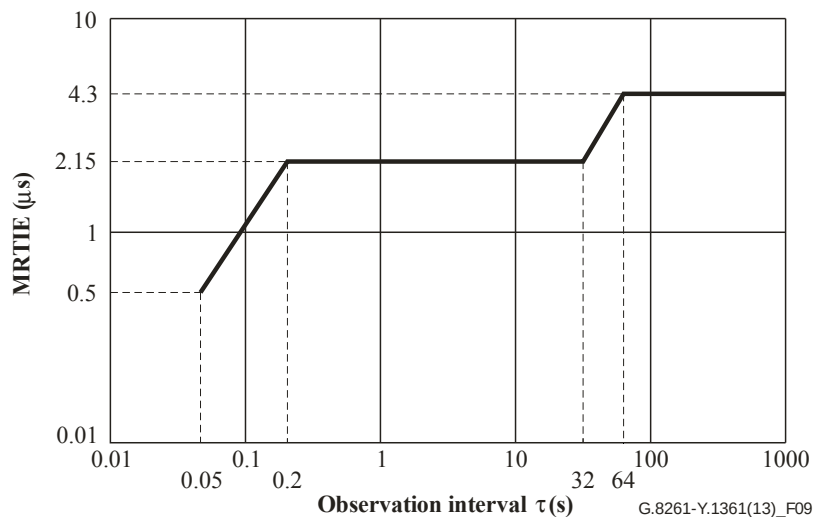


Figure 9 – Deployment Case 1: 2048 kbit/s interface wander budget

The 2048 kbit/s jitter network limits shall comply with clause 5.1 of [ITU-T G.823].

The wander budget, expressed in maximum time interval error (MTIE), for 1544 kbit/s signal is defined in Table 2. The resultant overall specification is illustrated in Figure 10.

Table 2 – Deployment Case 1: wander budget for 1544 kbit/s interface

Observation interval (τ) in seconds	MTIE in μ s
$\tau \leq 0.1$	No Requirement (see Note)
$0.1 < \tau \leq 0.47$	4.5τ
$0.47 < \tau \leq 900$	2.1
$900 < \tau \leq 1930$	$2.33 \times 10e-3 \tau$
$1930 < \tau \leq 86'400$	4.5
NOTE – This region is covered by jitter requirements.	

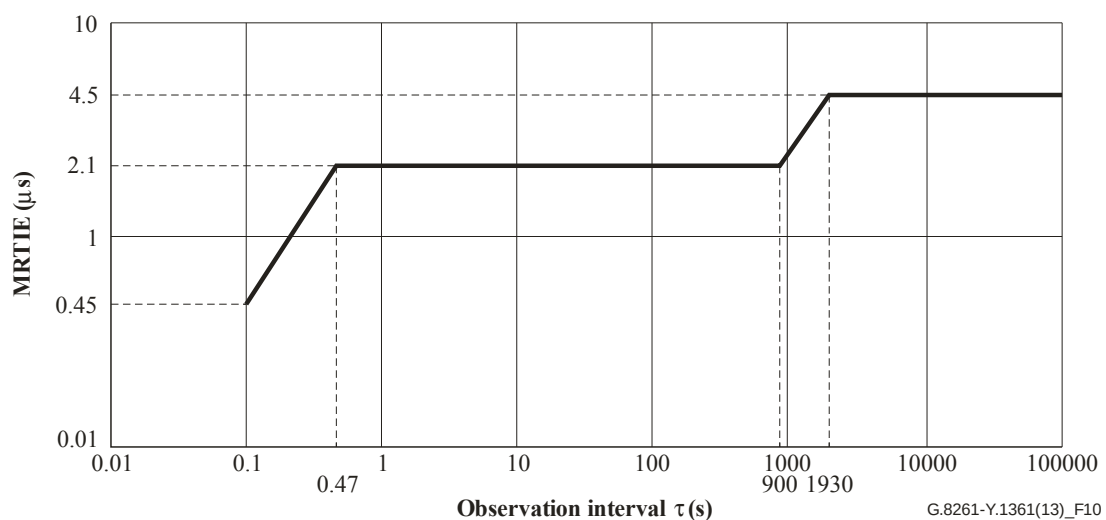


Figure 10 – Deployment Case 1: wander budget for 1544 kbit/s interface

The 1544 kbit/s jitter network limits shall comply with clause 5.1 of [ITU-T G.824].

NOTE – The network limits for the other PDH signals (i.e., 34'368 kbit/s, 44'736 kbit/s and 139'264 kbit/s signals) carried over the CES segments are for further study.

9.1.1.2 Deployment Case 2

Application A

When the CES segment is located outside the network elements containing the slip buffers (see Figure 8), the retiming effect of the switch has to be considered. At the output of this equipment, the timing of the traffic signal will meet the network limit for a synchronization signal which is tighter than for a traffic signal.

The jitter and wander budget of the CES segment in this case is the difference between the 2048 kbit/s network limit (see Figure 1 of [ITU-T G.823]) and the 2048 kbit/s synchronization interface network limit (see Figure 10 of [ITU-T G.823]). The limit, expressed in MRTIE, is provided in Table 3. The resultant overall specification is illustrated in Figure 11.

Table 3 – Case 2A: 2048 kbit/s interface wander budget

Observation Interval τ (s)	MRTIE requirement (μ s)
$0.05 < \tau \leq 0.2$	40τ
$0.2 < \tau \leq 32$	8
$32 < \tau \leq 64$	0.25τ
$64 < \tau \leq 1000$ (Note)	16
Note that for the asynchronous configuration, the maximum observation interval to be considered is 80 s. The specification between 80 s and 1'000 s for the asynchronous interfaces is for further study.	

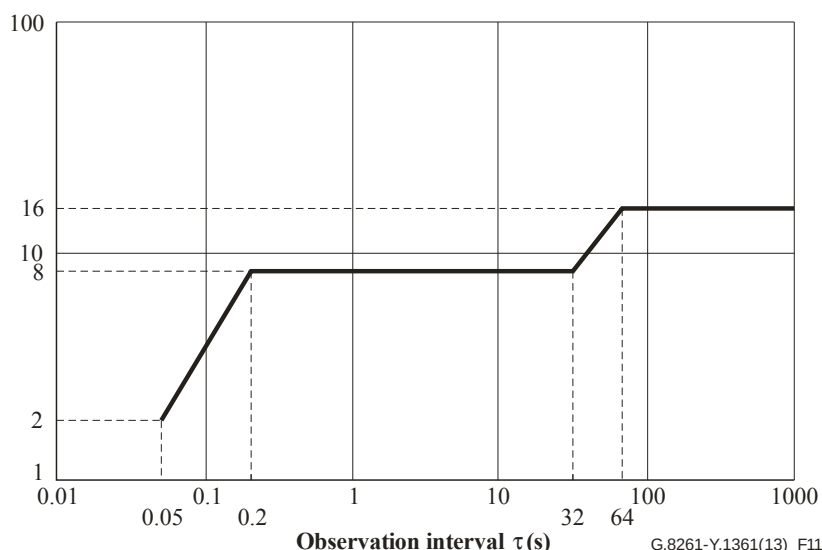


Figure 11 – Case 2A: 2048 kbit/s interface wander budget

In the case of 1544 kbit/s interfaces, Case 1 requirements also apply to Case 2 applications.

NOTE 1 – The network limits for the other PDH signals (i.e., 34'368 kbit/s, 44'736 kbit/s and 139'264 kbit/s signals) carried over the CES segments are for further study.

Application B

In this case, the application recovers timing through the TDM signal; therefore, there is no differential jitter and wander between the clock and the data other than within the bandwidth of the clock recovery since the data and clock are extracted from the same signal. The wander budget of the CES segment is only limited by the timing quality requested by the application (e.g., base station requirements) and not necessarily by [ITU-T G.823].

NOTE 2 – This application is valid only for applications with a single signal; if instead two signals are received, then the jitter and wander for one of those signals may differ from that of the clock extracted from the other signal.

9.1.1.3 Deployment Case 3

When retiming is implemented at the output of the SDH islands as shown in Figure 12, the amplitude of noise on the PDH output is that of a synchronization interface. This allows an increase in the wander budget up to that of Deployment Case 2 Application A in some configurations. It should be noted that the service clock is not preserved end-to-end in this case.

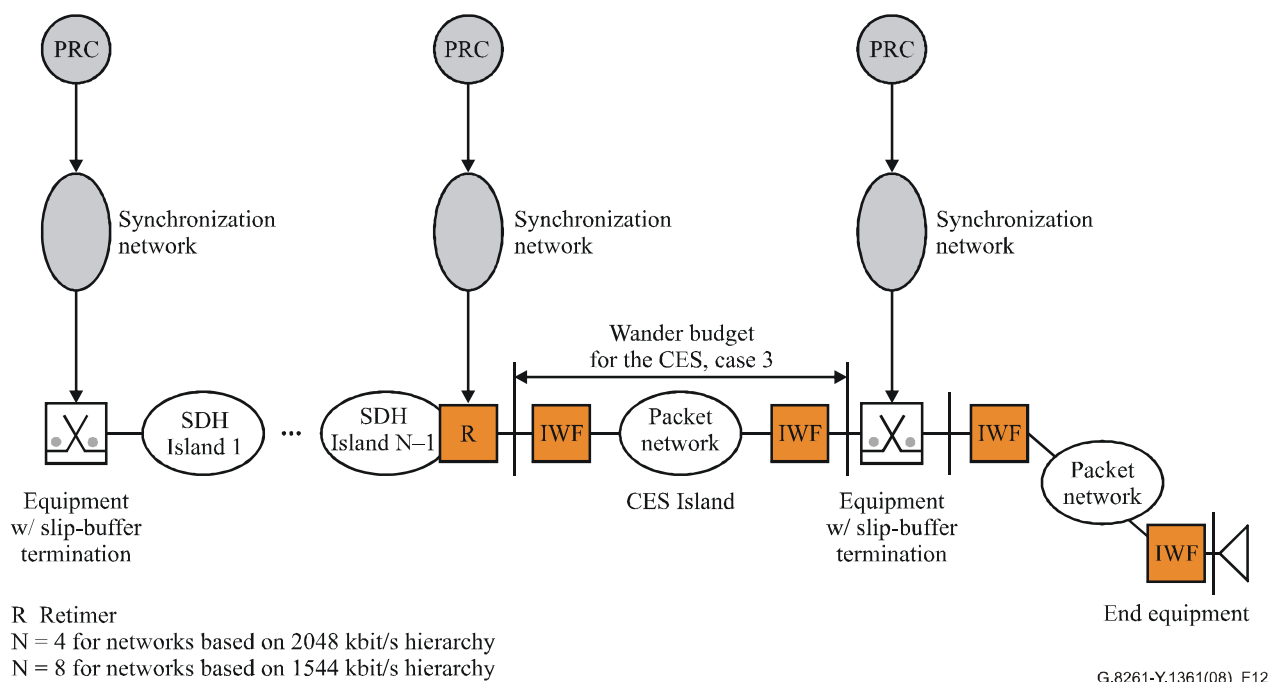


Figure 12 – Deployment Case 3 scenario

9.2 PNT network limits

The network models and the related network limits are defined separately for the case of the synchronous Ethernet (EEC interface) and in the case of the packet-based clocks (PEC interface).

In particular, details on the synchronization chains based on the synchronous Ethernet (e.g., number of the clocks in the synchronization chain) are according to the [ITU-T G.803], [ITU-T G.823] and [ITU-T G.824] models.

Some examples are provided in Figure D.1. As described in these examples, the network limits are defined in order to support hybrid implementations as well, where SDH is mixed with synchronous Ethernet.

NOTE – The network limits provided by this clause shall be valid under normal conditions (e.g., when failure conditions or maintenance actions are not present). It is out of the scope of this Recommendation to specify the proportion of time during which these limits apply.

9.2.1 EEC interface network limits

The network limits at the output of the EEC in a synchronization chain are defined in this clause.

NOTE – These limits are generally applicable at all points in the synchronization network. In some application cases, mainly in the access network, it might be possible to recover timing from an Ethernet signal that is generating jitter and wander according to the tolerance characteristics of the connected equipment (see Appendix IV for examples of relevant applications). The usage of an Ethernet link that does not comply with the limits defined in this clause is the operator's responsibility.

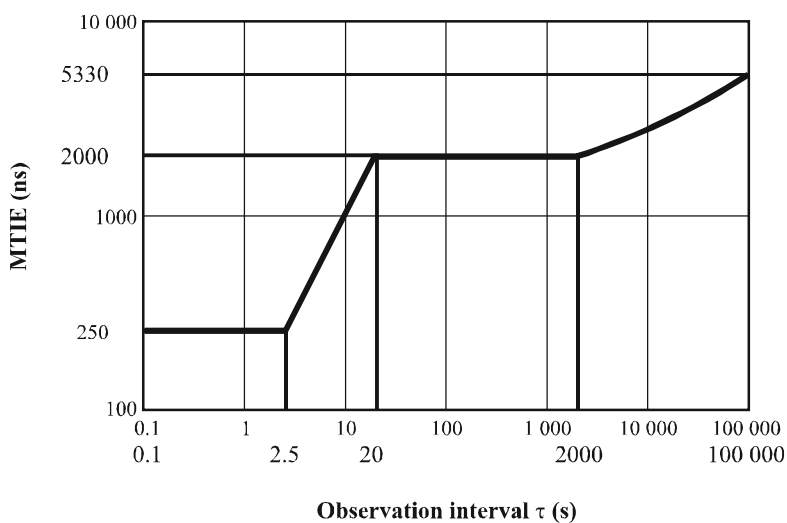
9.2.1.1 EEC-Option 1 interface network wander limits

The network limit for wander at the output interface of an EEC-1, expressed in MTIE, is given in Table 4. The resultant overall specification is illustrated in Figure 13.

NOTE – The values are relative to coordinated universal time (UTC), i.e., they include the wander of the PRC.

Table 4 – Network limit for wander at EEC-Option 1 interfaces expressed in MTIE

Observation interval τ (s)	MTIE requirement (ns)
$0.1 < \tau \leq 2.5$	250
$2.5 < \tau \leq 20$	100τ
$20 < \tau \leq 2000$	2000
$\tau > 2000$	$433 \tau^{0.2} + 0.01 \tau$



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Figure 13 – Network limit for wander (MTIE) at EEC-Option 1 interfaces

The network limit for wander at the output interface of an EEC-Option 1, expressed in time DEVIATION (TDEV), is given in Table 5. The resultant overall specification is illustrated in Figure 14.

Table 5 – Network limit for wander at EEC-Option 1 interfaces expressed in TDEV

Observation interval τ (s)	TDEV requirement (ns)
$0.1 < \tau \leq 17.14$	12
$17.14 < \tau \leq 100$	0.7τ
$100 < \tau \leq 1'000'000$	$58 + 1.2 \tau^{0.5} + 0.000 3 \tau$

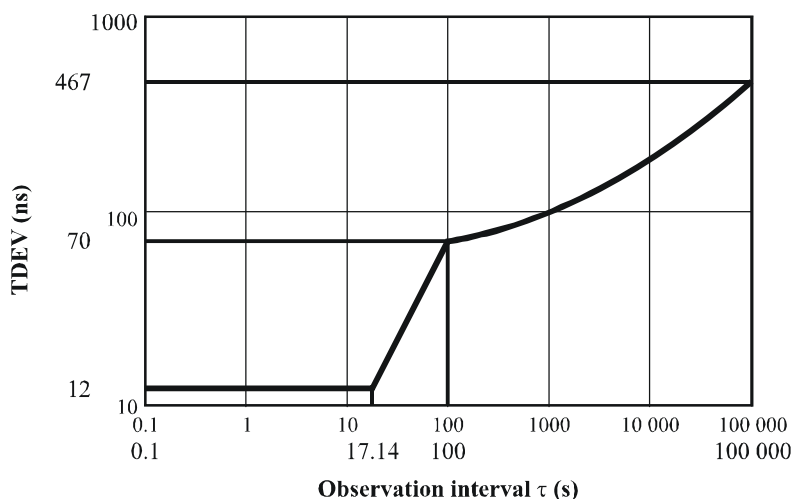


Figure 14 – Network limit for wander (TDEV) at EEC-Option 1 interfaces

9.2.1.2 EEC-Option 2 interface network wander limits

The network limit for wander at the output interface of an EEC-Option 2, expressed in TDEV, is given in Table 6. The resultant overall specification is illustrated in Figure 15.

Table 6 – Network limit for wander (TDEV) at EEC-Option 2

Observation interval, τ (s)	TDEV (ns)
$0.05 < \tau \leq 10$	10
$10 < \tau \leq 1000$	$3.1623 \tau^{0.5}$

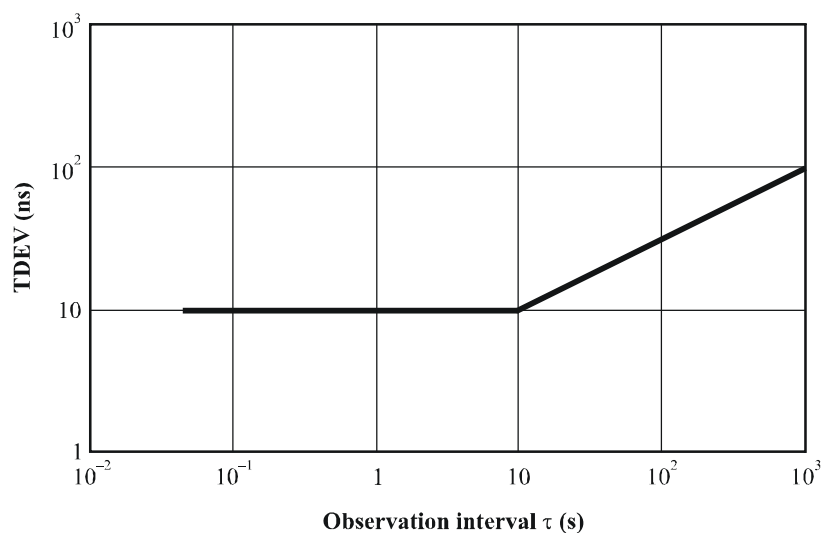


Figure 15 – Network limit for wander (TDEV) at EEC-Option 2

The mask in Figure 15 is taken from Figure 5 of [ITU-T G.824]. This mask is also found in Figure I.1 of [ITU-T G.813] for Option 2 Network wander limits.

9.2.1.3 EEC interface network jitter limits

See Table 7 for EEC interface network jitter limits.

Table 7 – EEC interface network jitter limits

Interface	Reference	
2048 kbit/s	See [ITU-T G.823], clause 6.1: Network limits for output jitter at synchronization interfaces, SEC requirements	(Note 1)
2048 kHz		
1544 kbit/s		
STM-n		
Ethernet (synchronous Ethernet)	See Table 7a	(Note 2)
NOTE 1 – Jitter limits are taken from [ITU-T G.823], [ITU-T G.824] and [ITU-T G.825] in order to allow proper interoperability with SEC based synchronization networks and combined EEC-SEC functions.		
NOTE 2 – In a chain of n ($n \leq 20$) connected EECs, the accumulated network jitter has to be low enough to allow all involved EECs to meet the output jitter specification at their synchronization outputs (e.g., 2048 kHz, 2048 kbit/s, 1544 kbit/s). See Figure 16 showing EECs in a chain; see also Annex D.		

Table 7a – Maximum permissible jitter at synchronous Ethernet network interfaces

Interface	Measurement bandwidth, –3 dB frequencies	Peak-to-peak amplitude (UI _{pp})
1 G (Notes 1, 2, 4)	2.5 kHz to 10 MHz	1.5
10 G (Notes 1, 3, 4)	20 kHz to 80 MHz	1.5

NOTE 1 – There is no specific high band jitter requirement for synchronous Ethernet. The relevant [IEEE 802.3] jitter requirements shall be met in addition to the specific synchronous Ethernet wideband jitter requirements specified in this table.

NOTE 2 – 1 G includes 1000BASE-KX, -SX, -LX; multi-lane interfaces are for further study.

NOTE 3 – 10 G includes 10GBASE-SR/LR/ER, 10GBASE-LRM, 10GBASE-SW/LW/EW; multi-lane interfaces are for further study.

NOTE 4 – 1 G 1 UI = 0.8 ns
10 G (10GBASE-SR/LR/ER,-LRM) 1 UI = 96.97 ps
10 G (10GBASE-SW/LW/EW) 1 UI = 100.47 ps

Figure 16 shows the reference chain of n ($n \leq 20$) EECs together with their synchronization outputs.

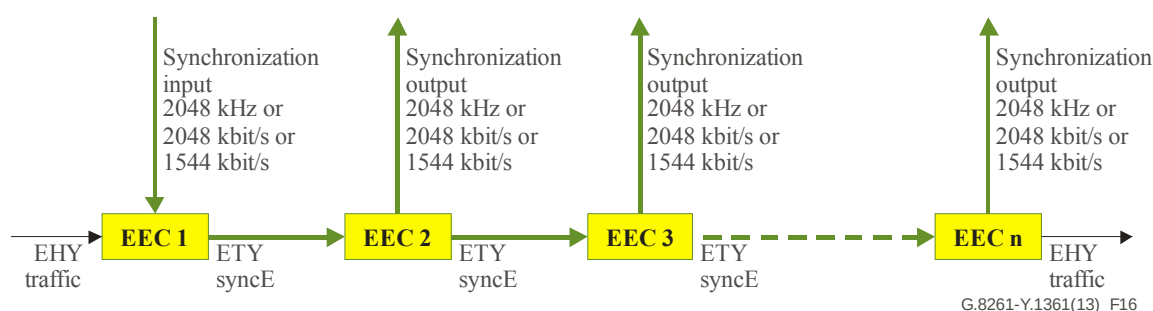


Figure 16 – EEC chain

9.2.2 PEC interface network limits

The network limits at the output of the PEC (see Figure B.5) are defined in this clause.

This clause describes two different deployment scenarios for a PNT segment or island with packet-based equipment clocks (PECs). The jitter and wander limits for the PEC interfaces are defined in this clause for each of these scenarios. Refer to [ITU-T G.8261.1] for network limits applicable at the input of the PEC.

9.2.2.1 Network model underlying the PEC network limits

For the transport of reference timing signals, the models in Figure 8-5 of [ITU-T G.803] and in Figure B.3 of [ITU-T G.823] are the starting point to consider the insertion of a PNT segment.

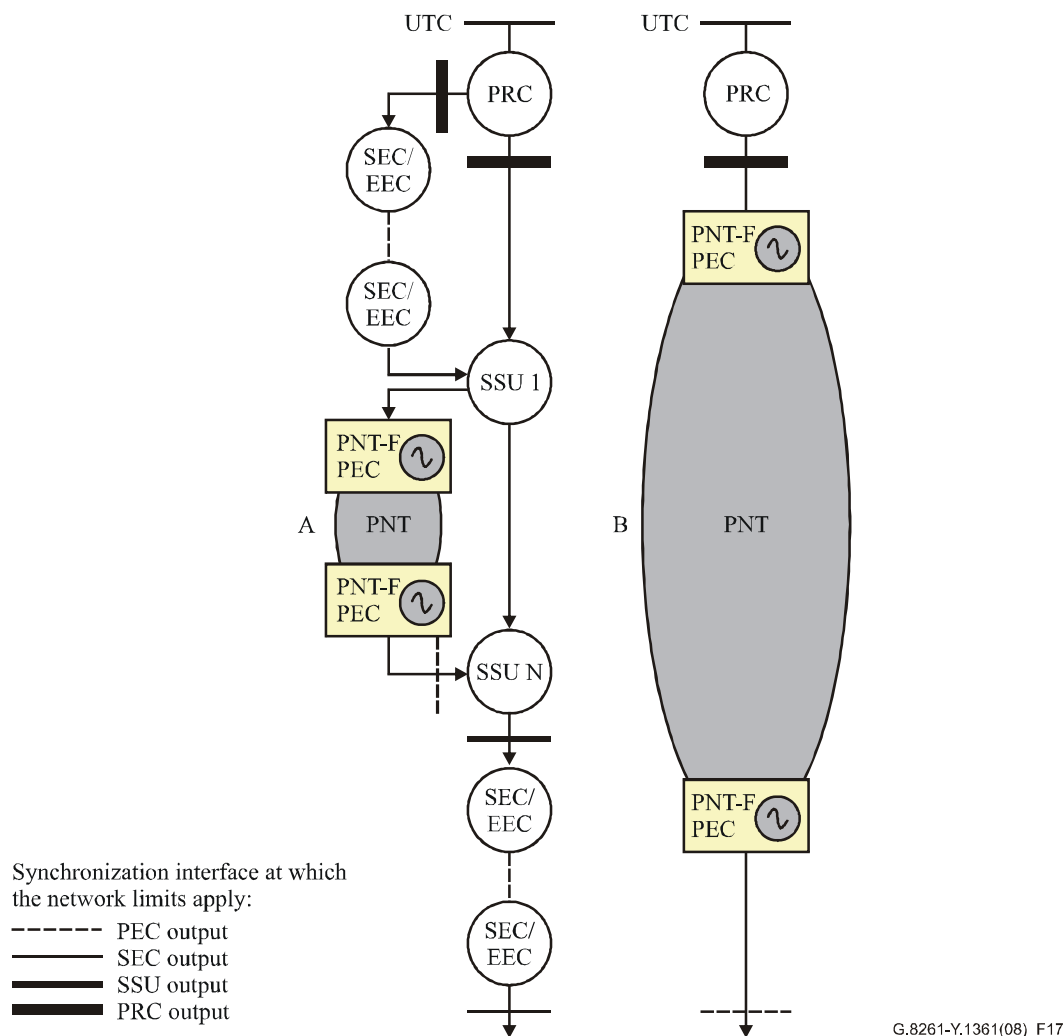
Depending on where the PNT segment is located, different wander requirements may apply. Several models of PNT deployment have been identified; the models are defined in this clause.

NOTE – The figures in this clause do not show the details on how the timing is distributed in the packet network. For further details, refer to clause 7.

PNT Deployment Case 1

The model for the PNT Deployment Case 1 is shown in Figure 17. This case relates to a master-slave synchronization network that, instead of using TDM based technologies (e.g., SDH or PDH), is implemented over packet-based network technologies.

The left figure (model A) shows an example where part of the synchronization network is replaced by a PNT segment, and the right figure (model B) refers to a synchronization network fully implemented over a PNT segment.



NOTE – The PEC is the PNT-F clock that is relevant in this model. The deployment of other clocks in the network (e.g., deployment of part of the PNT segment based on EEC and part on PEC) is for further study.

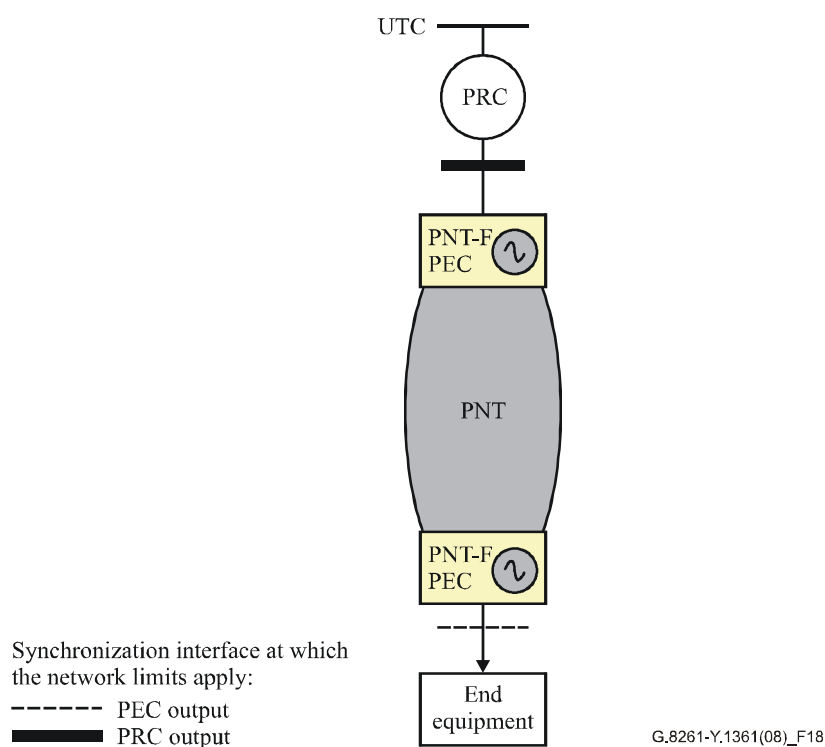
Figure 17 – PNT segment replacing part (model A) or all (model B) of the TDM-based synchronization network

The network limits as defined in clause 9.2.1 (EEC network limits) apply to both models A and B.

PNT Deployment Case 2

The model for the PNT Deployment Case 2 is shown in Figure 18.

This case is related to distributing the timing towards end equipment application (e.g., base transceiver station (BTS), see Appendix IV).



NOTE – The PEC is the PNT-F clock that is relevant in this model. The deployment of other clocks in the network (e.g., deployment of part of the PNT segment based on EEC and part on PEC) is for further study.

Figure 18 – PNT distributing timing towards end applications

In Deployment Case 2, the requirements are set by the end equipment. These are expressed in terms of tolerance and in terms of level of accuracy that the application requires for the correct operations.

Therefore, the PNT segment in Deployment Case 2 is allowed to generate jitter and wander up to the limits tolerated by the end applications (e.g., network limits for traffic interfaces as defined by clause 5 of [ITU-T G.823] or clause 5 of [ITU-T G.824]).

Further examples of network limits specifically applicable to the wireless applications are described in clause IV.2.3.

10 Impact of impairments in the packet network on timing distribution and service clock recovery

This clause discusses the different impairments impacting the traffic and its timing information in packet networks. It is understood that the requirements of emulated circuits and recovered clocks, which are specified in clause 9, are to be met under operational conditions.

Fundamentally, network synchronization is required in layer 1 networks to manage buffers. Layer 1 buffers as present in PDH, SDH and optical transport network (OTN) networks and its adaptation functions are simple structures, where the nominal ingress and egress rate is controlled within specific bounds as given in the related networking standards of these TDM networks. Mechanisms, such as stuff bytes and pointers, together with system clocks, are the methods used to manage these buffers and accommodate different clocking domains. The network design constrains the buffer size to minimize latency. In layer 1 networks, such as SDH, there is a direct linkage between the network clock and the level of wander or jitter that may be imparted on a client signal.

In the case of packet data networks transport, the data is delivered over the network in blocks (packets, frames), rather than being carried as a continuous stream of constant bit rate. Packets may be statistically multiplexed and are routed via packet switches which subject a packet to delay due to processing, buffering and retransmission at intermediate switches. Within a single switch, multiple packet streams may have to converge onto a single output buffer. The resulting buffer contention will introduce variable delay. In some cases, packets will be dropped. The clock used to drive the layer 1 transmission links is likely to be asynchronous to the clock used within the switch. Any difference in the rate at which packets are presented for transmission and the actual transmission rate is accommodated by adding padding between packets or discarding packets.

Since packets may traverse different routes, a stream of packets from ingress to egress may exhibit significant packet delay variation. Additionally, packets may be misordered resulting in additional buffering. Services that utilize the packet network need to consider these impairments. For packet networks, large buffers are required to perform packet level processing, in which case only coarse levels of synchronization are required to support most services.

Unlike a layer 1 network, such as SDH, there is no direct linkage between the network clock and the packet processing buffers. Thus, network timing cannot be used to control packet delay variation in these networks. The need to provide network synchronization to a packet switch is generally required only to meet synchronization requirements for physical layer interfaces to the switch, in accordance to the related TDM interface requirements, as given by the particular networking standards such as SDH/PDH.

Timing requirements of services carried at layers above the layer 2 network (e.g., IPTV, MPEG-4) are specified to accommodate the variations of existing packet networks. Any service specific timing is encoded at the service layer (e.g., H.264, MPEG-4).

However, there are cases when the physical layer of a packet network is synchronous (e.g., SDH) and may be utilized by the adaptation layer.

In most cases, the information carried across the packet network, i.e., the characteristic information, does not include timing information. This has certain ramifications when services require the transfer of accurate timing. For end-to-end services, the timing characteristics of the server layer need to support the synchronization requirements of the client. In traditional layer 1 mechanisms (PDH, SDH and OTN), the network timing adaptation mechanisms are specifically designed to be compatible with the timing requirements of the client signal. When the server layer is incapable of supporting the timing of the client, alternate means of providing client timing may be required. This would be performed at the adaptation layer to the network. An example is ATM AAL1.

Impairments in the packet network may have a detrimental effect on the recovery of the service for a clock using adaptive methods. This clause explores the levels of such impairments that a clock recovery process should be capable of withstanding, while maintaining the clock within the relevant specifications.

The following performance parameters relating to packet network impairments are defined in [ITU-T Y.1540] (for IP networks) and [ITU-T Y.1561] (for MPLS networks). Similar performance measures for Ethernet networks are also defined in [ITU-T Y.1731].

- 1) packet transfer delay and delay variation
- 2) packet error ratio
- 3) packet loss ratio
- 4) packet severe loss block outcomes.

10.1 Packet transfer delay and delay variation

10.1.1 Differential methods

Packet transfer delay and delay variation should not affect clock recovery performance when a network reference clock is available at both ends and differential methods are used.

10.1.2 Adaptive methods

Adaptive recovery of the service clock from a packet stream containing constant bit rate or timestamp data is, in general, achieved by some computing function of the arrival rate or arrival times of the packets at the destination node.

If the delay through the packet network is constant, the frequency of arrival of packets at the destination node is not affected by the network. There may be a phase lag in the recovered clock due to the delay through the network, but there should be no frequency or phase wander.

If the delay varies, it may be perceived by a clock recovery process as a change in phase or frequency of the original service clock. Therefore, during the design of a clock recovery process, the causes of delay variation must be considered carefully.

There are several causes of delay variation on a packet network. These may include:

- random delay variation (e.g., queuing delays)
- low frequency delay variation (e.g., day/night patterns)
- systematic delay variation (e.g., store-and-forward mechanisms in the underlying transport layer)
- routing changes
- congestion effects.

10.1.2.1 Random delay variation

Random variation in delay results from the behaviour of switches or routers in the packet network. The primary source of this is output queuing delay, caused when a packet arrives at a switch or router when the exit port is blocked by other traffic, and the packet has to wait in a queue. Other factors caused by the internal operation of the switch or router may also delay the packet, as described in Appendix I.

It is not possible to predict with any certainty the delay of any packet through a switch or router, although it is likely that the delay will increase with load on the device. Therefore, there will be some correlation of delay between successive packets with the traffic load in the network.

10.1.2.2 Low frequency delay variation

As described above, the delay through a packet network, although unpredictable, is generally correlated with the load on the network at the time period in question. Load is a dynamic quantity, and may contain extremely low frequency components. For example, if a network is more heavily loaded during the day than at night, this gives a component to the load variation with a 24-hour period.

This extremely low frequency variation may lead to phase wander in a clock recovered from a packet stream with the same period. Since many of the relevant clock specifications limit the permissible phase wander over periods of 24 hours or more (e.g., [ITU-T G.824]), this has to be compensated for during the design of a clock recovery process.