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Synchronization as a service

How to provide phase and time of day information using Precision Time Protocol (PTP) over a transport network: challenges and solutions

White paper

As services in telecommunications networks evolve and continue to require tight equipment time synchronization that is driven mainly by mobile LTE-A technologies and the further evolution to 5G, operators are starting to look at ways to distribute absolute time of day information in their networks. While different options exist, it is natural to question if the transport network can be leveraged for such a purpose because it is part of the common, pervasive and low-level infrastructure and is already used for frequency transport. Yet, while the final answer to this question is yes, thinking that because the optical transport network/wavelength division multiplexing (OTN/WDM) technology is by design transparent to frequency and that it will be transparent to phase and time of day as well, is a naïve approach that utterly fails. This white paper explains the need for phase and time of day alignment, the underlying challenges in providing a synchronization as a service over the transport network, and the available solutions provided by the Nokia 1830 Photonic Service Switch (PSS) family.

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Introduction

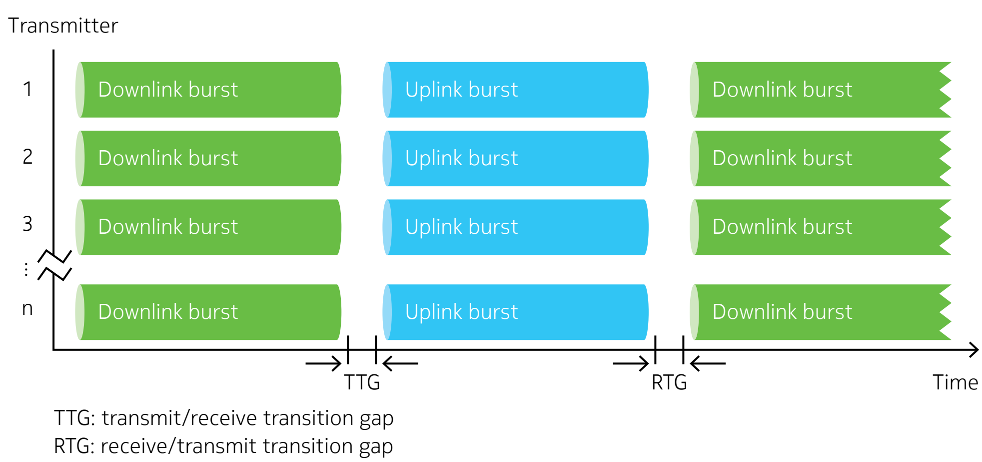
Time for timing

Services in telecommunications networks are evolving and require stringent equipment time synchronization, driven mainly by mobile LTE-A technologies and the future evolution to 5G. In a nutshell, the different mobile cells must be aligned in absolute time as well as in frequency to be able to coordinate the transmission and reception of the data from multiple stations to the mobile end user.

In particular, Long Term Evolution time division duplex (LTE-TDD) mobile technologies such as time division synchronous code division multiple access (TD-SCDMA) and code division multiple access 2000 (CDMA2000); and the LTE-A features, such as enhanced Multimedia Broadcast Multicast Services (eMBMS), coordinated multipoint (CoMP) and enhanced inter-cell interference coordination (eICIC), are based on the assumption of strict time and phase alignment between the different mobile cells. Phase information is also required for the equalization of delay in the uplink and downlink directions which often have very tight symmetry requirements.

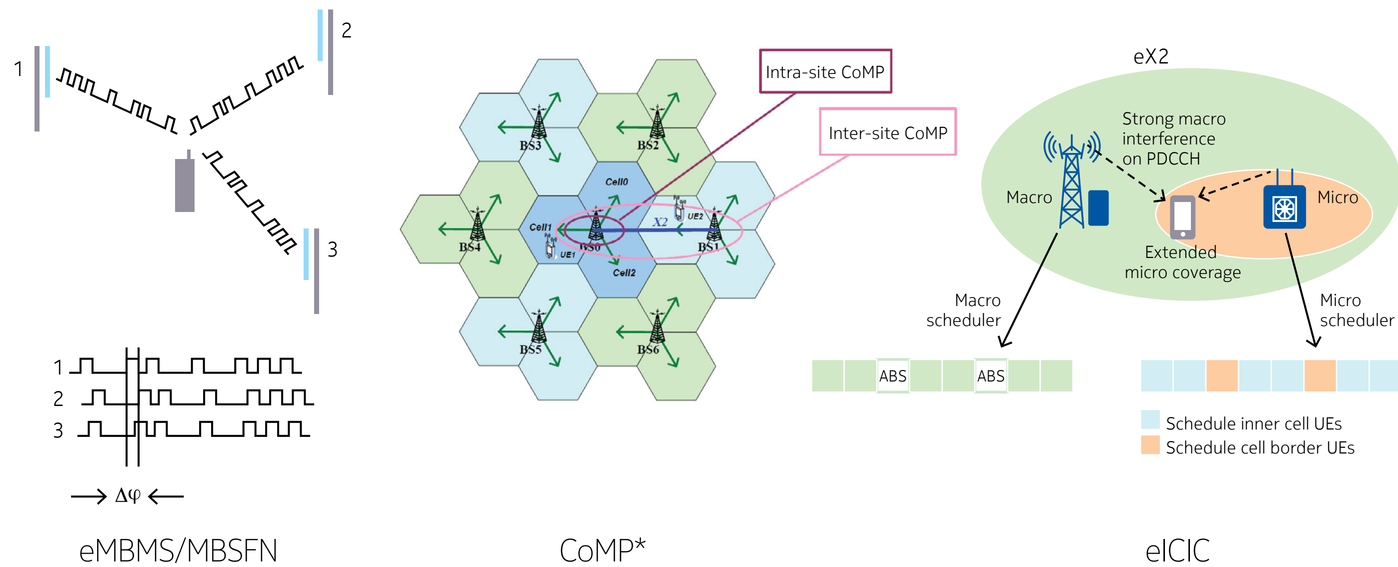
LTE-TDD uses time division duplex transmission (in contrast to LTE-FDD, which uses frequency division duplex transmission), exploiting a single frequency alternating between uploading and downloading data over time. Thus, LTE-TDD (as well as TD-SCDMA and CDMA2000) at its inception has required tightly time-aligned frames to ensure that there is no overlap of transmission blocks.

Figure 1. LTE-TDD phase synchronization



Enhanced MBMS is the LTE version of the Multimedia Broadcast Multicast Services (MBMS) already existing for 3GPP. Multicast broadcast single-frequency network (MBSFN) is used by eMBMS for transmitting the same synchronized signal from multiple eNodeBs to multiple user equipment (UE) (for example, handsets) over a single frequency. The MBSFN transmission appears to the UE as coming from a single large cell, thus improving the signal-to-noise ratio (SNR) and the signal-to-interference ratio (SIR) due to the absence of intercell interference. Time synchronization is key because the signals must be very close in time at the handset for the combination to be constructive.

Figure 2. LTE-A features requiring phase/time synchronization (CoMP, eMBMS, eICIC)



* Source: "4G mobile broadband evolution" report Figure 6.1, page 88.

Coordinated multiPoint (CoMP) is a set of techniques used to achieve high data rates also at the edges of the eNodeB cells, where the signal is lower in strength and interference from neighboring eNodeBs is higher. CoMP requires close alignment between a number of separate eNodeBs that must coordinate joint transmission and reception. Consequently, the UE can be served by more than one eNodeB, improving reception and transmission and increasing throughput. The cell coordination also requires tight time synchronization between the eNodeBs.

eICIC is used in heterogeneous networks (HetNets) to minimize the interference of a macro cell to a micro cell. The macro cell from time to time transmits almost blank subframes (ABSs), and in this time period the micro cell can communicate with the UE with reduced interference. Time synchronization between the macro and the micro cells is then mandatory for this mechanism to work.

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Time synchronization tools

A global navigation satellite system (GNSS) (for example, the global positioning system [GPS]) is a simple choice for phase/time synchronization as it can deliver, under normal working conditions, a maximum absolute time error around +/- 0.1 ms. However, GNSS receivers need antennas, which are subject to disturbances and possible jamming. These receivers rely on satellite constellation systems that are under the control of various goverment agencies and could be disabled (or dithered producing degraded accuracy) at any time. The only alternative to satellite system receivers available today is the IEEE 1588-2008 protocol that is also known as IEEE 1588v2 or Precision Time Protocol.

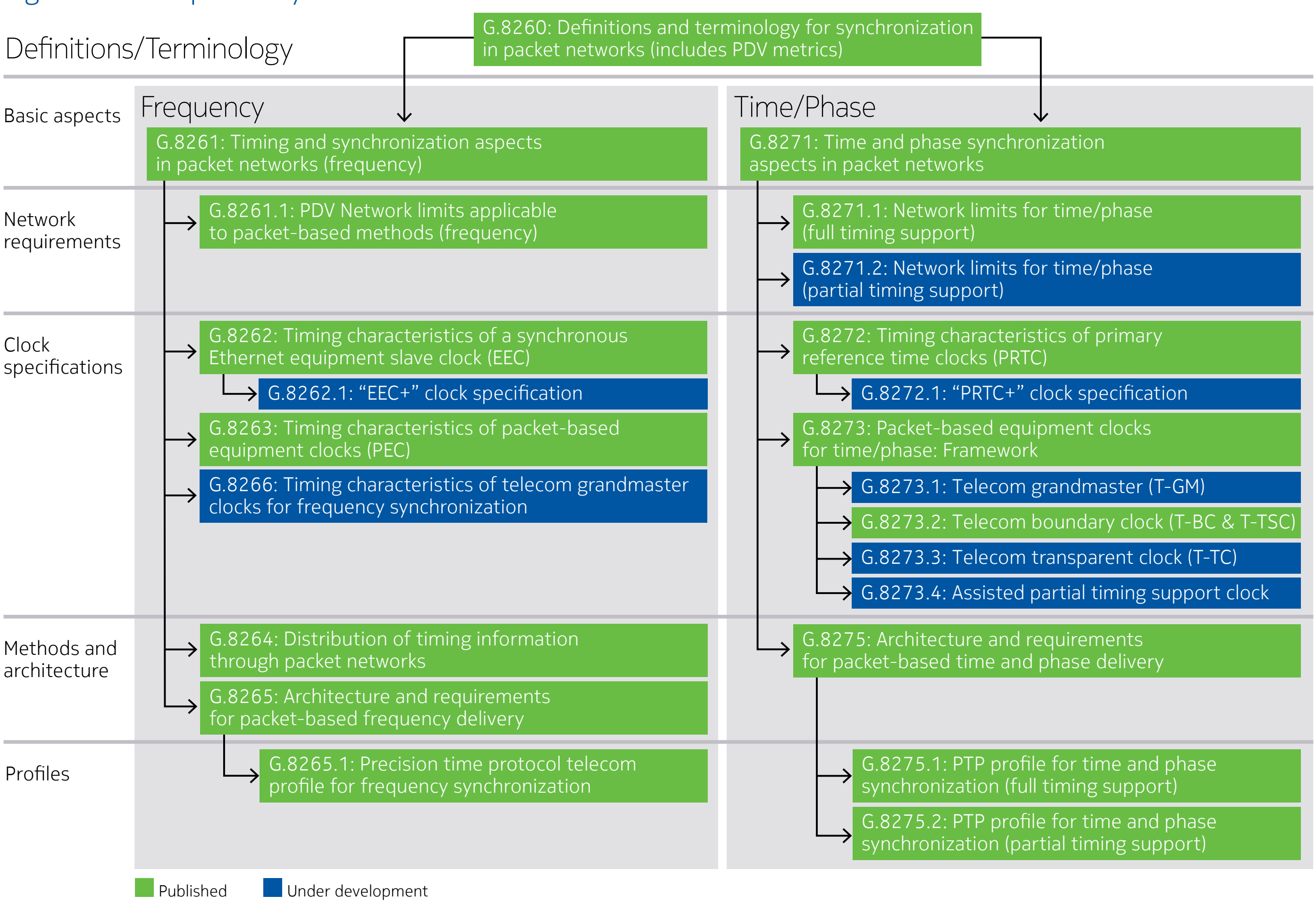
The IEEE 1588-2008 standard defines a network protocol enabling accurate and precise synchronization of the real-time clocks distributed in different locations. The clocks communicate with each other over a communications network that can be based on, but is not limited to, Ethernet protocol. Note though that IEEE 1588-2008 is a packet protocol, so it requires by its nature some packet-processing functions. The protocol enables heterogeneous systems that include clocks of various inherent precision, resolution, and stability to synchronize to a telecom grandmaster (T-GM) clock. The protocol supports systemwide synchronization accuracy in the sub-microsecond range.

Telecommunications timing requirements

IEEE 1588-2008 is a general standard and is being used in many domains, such as telecommunications, power distribution, transportation, military, telesurgery and time-sensitive measurement. For example, it is used in the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. To address all of these different domains, the IEEE 1588v2 standard introduced the concept of a “profile,” whereby aspects of the protocol may be selected and specified for a particular use. Among these industries, the telecommunications industry has a keystone role in using time/phase synchronization capabilities. As a consequence, two PTP profiles have been defined by ITU-T (that is, ITU G.8265.1 and G.8275.1) to address telecom applications requiring frequency synchronization and time/phase synchronization, respectively.

In the context of this white paper the focus is on the G.8275.1 profile, which defines a full timing support for time/phase synchronization. Note that the parameters defined in the G.8275.1 profile assume that physical layer frequency support is provided. This means that proper phase synchronization through IEEE 1588v2 requires frequency synchronization of the nodes using ITU G.8261 Synchronous Ethernet (SyncE). The PTP telecom profile defines the parameters from IEEE 1588v2 that are used to guarantee protocol interoperability between implementations. It also specifies the optional features, default values of configurable attributes and mechanisms that must be supported. However, similar to IEEE 1588v2 it does not guarantee that the performance requirements of a given application will be achieved.

Figure 3. ITU-T packet synchronization-related standards



Timing requirements of mobile networks

Table 1 summarizes the main requirements of timing for mobile technologies, as per relevant standards. These limits are end to end.

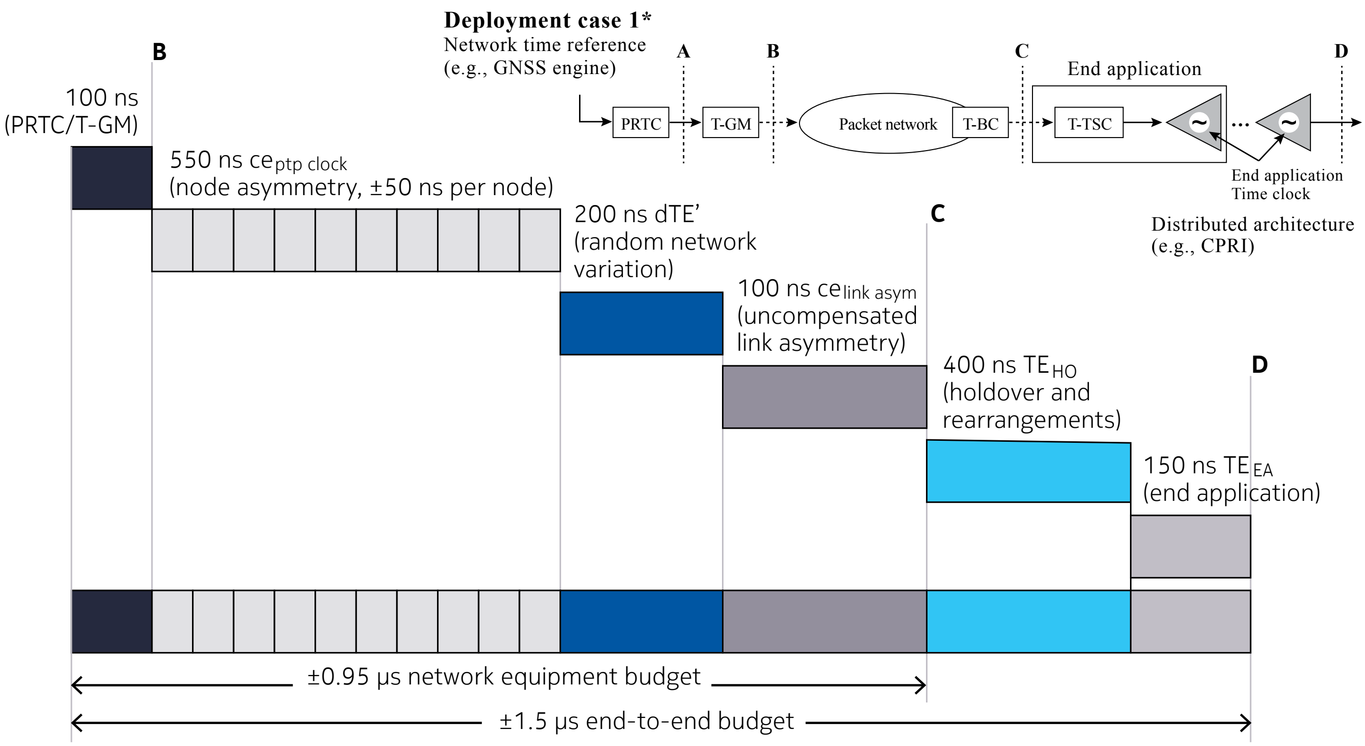
Table 1. Requirements of timing for mobile technologies

eNodeB synchronization options		Synchronization requirement		Synchronization method			
		Frequency	Phase	GPS/GLONASS	IEEE 1588v2		SyncE
					Frequency only	Frequency+phase	
Base technology	LTE FDD	50 ppb[2]		OK	OK	OK	OK
	LTE TDD	50 ppb	1.5 µs	OK		OK	
Features requiring phase synchronization	Measurement based HO to eHRPD/e1xCSFB		10 µs	OK		OK	
	OTDOA for E911[1]		100 ns	OK		Not OK	
	eMBMS		1.5 µs	OK		OK	
	eICIC		1.5 µs	OK		OK	
	CoMP (CSCB)		1.5 µs	OK		OK	

1. OTDOA for E911 is required for VoLTE service in North America, but can be optional for indoor cells with small cell radius.
2. For local area BS - power <=24 dBm frequency accuracy requirements are of 100 ppb as per 3GPP TS36.104.

The ITU-T G.8271 standard provides examples of how the overall end-to-end timing limits on phase can be allocated into different components. Figure 4 illustrates the overall expected contribution to the phase error of each network element in a chain is in the order of 50 ns.

Figure 4. An example of time error allocation for Appendix V, Scenario b) and Class A T-BC



* Source: G.8271.1, Figure 7.1.

Challenges for IEEE 1588v2 PTP in the transport network

IEEE 1588v2 PTP principle

The principle of IEEE 1588v2 is based on the exchange of a time stamped packet between a master and a slave clock. Assuming that there is a fixed offset between the clock of the master and the clock of the slave, and that there is a fixed delay in the transmission from master to slave and vice versa, a simple algebraic calculation based on the time stamps can derive the delay and the offset values.

IEEE 1588-2008 was intended for deployment in packet networks. However, the extension to OTN and WDM networks and the distinct nature of these technologies imposes special measures which will be discussed in the next sections.

Fixed asymmetry is bad

By definition the IEEE 1588-2008 protocol assumes a symmetrical delay between master and slave clocks. If this delay is asymmetric, the PTP algorithm still works, but the asymmetry introduces an error that is one half of the delay difference (that is, asymmetry). But what are the sources of asymmetry, and is asymmetry really playing a role?

One of the most direct sources of asymmetry is the fiber length difference between the transmission (TX) and reception (RX) sides. While the length of the fibers in a cable is mostly uniform, in the telecom stations the fiber may have been spliced and connectorized at different lengths. Considering that light travels at about 20 cm/ns into a fiber, a length difference of 10 m would introduce a 50 ns/2 = 25 ns error, which is non-negligible with respect to the already discussed ITU G.8271.1 example requiring a per-node time budget allocation of about 50 ns. Nevertheless, IEEE 1588v2 PTP can still work by compensating the fixed asymmetry, by using a static correction parameter in the algorithm. This requires asymmetry measurements with additional complexity and works only as long as the asymmetry is static. Other sources of static asymmetry could come from amplifiers, dispersion compensation modules and wavelength dependent delays.

Dynamic asymmetry is worse

From the previous discussion it is clear that fixed asymmetry is not desirable, but even though it is unavoidable in most cases, the fixed asymmetry can be compensated. Unfortunately, in a modern fiber optic telecommunications network, there are sources of asymmetry that change over time, possibly even rather quickly.

Sources of dynamic asymmetry in a packet network are most often associated with a buffering stage like queues and fiber first in first outs (FIFOs) internal to the packet processing and/or switching architecture of a system.

When packets are transported transparently over an agile, flexible OTN/WDM network, the main sources of asymmetry are due to the OTN muxing and switching of signal in the electrical domain, and the rearrangement of the wavelengths through the reconfigurable optical add-drop multiplexer (ROADM) in the optical domain.

In the electrical domain, as also demonstrated by the measurements described in the ITU Study Group 15 – Contribution 0685, “Test and Analysis about PTP over OTN in Transparent Mode,” April 2014, the time accuracy measurement shows significant degradation (in the order of microseconds) when intermediate OTN cards or nodes are reset. Other reasons why the transparent transport of PTP through a G.709 OTN network leads to degraded timing performance are the variable asymmetries introduced by FIFOs and by the OTN switch itself.

In the optical domain, operations like protection and restoration of unidirectional links can change the optical length of the paths, and photonic layer restoration with Generalized Multiprotocol Label Switching (GMPLS) cause sudden changes in the optical link asymmetries.

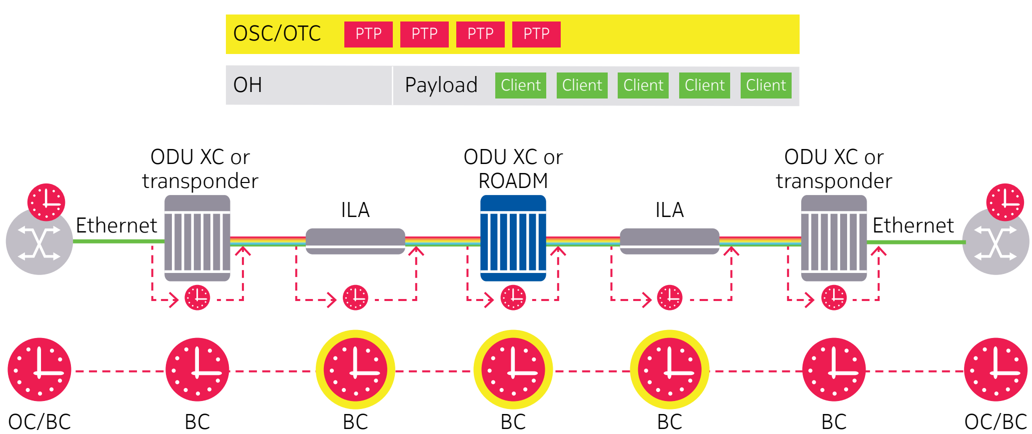
In general, it is very difficult to characterize when a transparent timing transport over OTN/WDM may work, for how many hops and under which conditions.

Solutions with Nokia 1830 PSS

Optical timing channel

The challenges that were discussed earlier demand a serious alternative to the naïve transparent transport of PTP over OTN. A robust, field-proven solution that completely tackles these challenges is the definition of an optical timing channel (OTC) dedicated to the transport of the phase information, while frequency is locked using SyncE. PTP is then transported over a separate optical wavelength and terminated at each WDM span. In this way, PTP can be treated in a dedicated way, minimizing timing errors. Higher performance can be achieved by automatically measuring and compensating the static link asymmetry for each span, and by mitigating the sources of dynamic link asymmetry because the main asymmetry-generating blocks are completely bypassed. Nokia can provide the full solution for OTC PTP transport in the Nokia 1830 PSS family to achieve the best performance, cost, and complexity trade-off in a metro core OTN/WDM network.

Figure 5. IEEE 1588v2 over optical timing channel (PTP over OTC)



OCH overhead

Another possible way to avoid full transparent transport of PTP is leveraging the optical channel (OCH) overhead. ITU-T recently allowed G.709 Amendment 4 to support an OTN synchronization messaging channel (OSMC) byte for the transport of PTP over optical channel transport unit-k overhead (OTUk OH).

However, Nokia is not supporting this partial solution because:

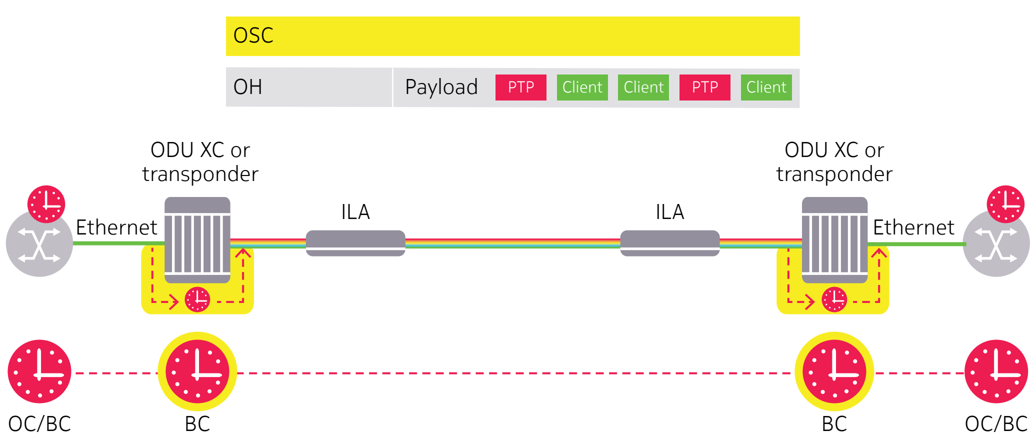
- PTP over OTUk OH requires a physical layer synchronization technology, aligning the physical layer OTUk signal to a traceable clock similar to Synchronous Digital Hierarchy (SDH), thus contradicting the original concept of OTN as an asynchronous technology.
- PTP over OTUk OH, as per the ITU-T standard, should be supported only on interdomain interfaces, such as OTUk client interfaces, and not on intradomain interfaces that limit its applicability.

Layer 2 transparent client transport of PTP

In metro aggregation/access networks, where Nokia Ethernet Layer 2 cards are used for delivery of Metro Ethernet Forum (MEF) services, a simple alternative to the full OTC solution is possible. In this case, if the metro/access WDM network is a standard fixed optical add-drop multiplexer (OADM) network, the IEEE 1588v2 solution embedded on the Layer 2 cards would work because it is a hop-by-hop solution. Thus, PTP is terminated at each node in a Layer 2 card with transport boundary clock (T-BC) capabilities, and SyncE is used for frequency lock.

Optical link asymmetry or dispersion compensating fiber (DCF) is static and can be compensated through link asymmetry correction as supported in the Nokia implementation of the IEEE 1588v2 algorithm. The advantage of this solution, while less performing than PTP over the OTC, is the inherent capability of the Nokia Ethernet Layer 2 cards to support IEEE 1588v2. Consequently, no additional hardware assets are needed and there is no impact on the WDM line engineering rules and planning. The simplicity of this solution makes it very attractive for many applications toward the edge of the network where simple OTN/WDM transport is required.

Figure 6. IEEE 1588v2 in Layer 2 transparent client transport (PTP in payload)



Summary

The evolving telecommunications networks require stringent equipment time synchronization, and on the path to LTE-A and 5G these requirements will become mandatory. However, proper delivery of the time of day information with nanosecond accuracy poses serious challenges to the telecommunications network. These challenges cannot be addressed with naïve approaches, but require proper attention. Nokia provides the solutions needed to deliver synchronization as a service with the performance, quality and reliability expected by the end users.

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10. IEEE Std 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

Acronyms

3GPP	Third Generation Partnership Project
ABS	almost blank subframe
BC	boundary clock
CDMA	code division multiple access
CERN	Conseil Européen pour la Recherche Nucléaire (European Organization for Nuclear Research)
CoMP	coordinated multipoint
CPRI	Common Public Radio Interface
CSFB	circuit switched fallback
DCF	dispersion compensating fiber
eHRPD	evolved high rate packet data
eICIC	enhanced inter-cell interference coordination
eMBMS	enhanced Multimedia Broadcast Multicast Services
FIFO	first in first out
GLONASS	global navigation satellite system (Russian GPS)
GM	grandmaster
GMPLS	Generalized Multiprotocol Label Switching
GNSS	global navigation satellite system
GPS	global positioning system
HetNet	heterogeneous network
HO	handover
IEEE	Institute of Electrical and Electronics Engineers
ILA	in-line amplifier
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
LHC	Large Hadron Collider
LTE-A	Long Time Evolution Advanced
LTE-FDD	LTE frequency division duplex
LTE-TDD	LTE time division duplex
MBMS	Multimedia Broadcast Multicast Services
MBSFN	multicast broadcast single-frequency network
MEF	Metro Ethernet Forum
OADM	optical add-drop multiplexer
OC	ordinary clock
OCH	optical channel
ODU	optical channel data unit
OSC	optical supervisory channel
OSMC	OTSn OTN synchronization messaging channel
OTC	optical timing channel
OTDOA	observed time difference of arrival
OTN	optical transport network
OTS	optical transmission section
PRTC	primary reference time clock
PSS	Photonic Service Switch
PTP	Precision Time Protocol
ROADM	reconfigurable optical add-drop multiplexer
RTG	receive/transmit transition gap
SDH	Synchronous Digital Hierarchy
SIR	signal-to-interference ratio
SNR	signal-to-noise ratio
SyncE	Synchronous Ethernet
T-BC	telecom boundary clock
TDD	time division duplex
TD-SCDMA	time division synchronous code division multiple access
T-GM	telecom grandmaster
TTG	transmit/receive transition gap
T-TSC	telecom time slave clock
UE	user equipment
VoLTE	voice over LTE
WDM	wavelength division multiplexing
XC	cross-connection

Nokia Oyj
Karaportti 3
FI-02610 Espoo
Finland
Tel. +358 (0) 10 44 88 000

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