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Synchronous Ethernet to Transport Frequency and Phase/Time

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Abstract

This article describes how Synchronous Ethernet technology provides a solution for transporting synchronization over Ethernet. Synchronous Ethernet uses syntonization/frequency synchronization from the physical layer together with a slow protocol and has been standardized by the ITU-T for frequency distribution. This article also describes how Synchronous Ethernet could be extended in order to transport phase/time in addition to frequency; this is referred to as "Time Synchronous Ethernet" (TSE) in this article.

Synchronous Ethernet Background

Synchronous Ethernet was first proposed by operators to ITU-T Study Group 15 in 2005. At that time work on ITU-T Recommendation G.8261 was starting and several options to transport synchronization were being discussed. Using the capability of the Ethernet link to transport synchronization just as in SDH/SONET was highly desirable.

Analysis indicated that the Ethernet physical layer was capable of transporting synchronization without requiring any change to IEEE802.3. Synchronous Ethernet requires the clock to operate with a frequency tolerance range of ±4.6 ppm, which is within the specifications defined by IEEE802.3 (±100ppm).

Synchronous Ethernet Principle of Operation

The transport of synchronization using the physical layer is not a new concept. SONET/SDH uses clock recovery from the data stream. SONET/SDH also defines a clock hierarchy where the first node is externally timed to a Primary Reference Clock (PRC) and the nodes downstream are line timed and propagate the timing.

A key decision was made at ITU to have Synchronous Ethernet interwork with the SONET/SDH synchronization hierarchy. This was very important for operators to facilitate the management of the synchronization network. Several standards were developed for Synchronous Ethernet dealing with architecture, clock quality, protection switching, etc. They are:

Recommendation G.8261: First released in 2006 and included the concept of Synchronous Ethernet. A new revision was released in 2008, and includes the architecture aspects of Synchronous Ethernet as well as Wander Network limits. The Wander Network limits were defined to be compatible with SONET/SDH networks allowing hybrid implementation where SONET/SDH is mixed with Synchronous Ethernet. Annex A of G.8261 proposed a network architecture for Synchronous Ethernet. Amendment 1 was consented in June 2010 that included network jitter limits for the Synchronous Ethernet Interface.

Recommendation G.8262: First released in 2007 and defines the Synchronous Ethernet Equipment Clock (EEC). It defines two types of EECs, option 1 and option 2. EEC-option1 is used in equipment designed for networks optimized for the 2048-kbit/s hierarchy and is based on the SDH Equipment Clock (SEC) defined in ITU-T Recommendation G.813. EEC-option2 is used in equipment designed for networks optimized for the 1544-kbit/s hierarchy and is based on the Type IV clock defined in ITU-T Recommendation G.812 and is equivalent to Stratum 3 in North America. Amendment 1 to G.8262 was consented in February 2012 and adds an Appendix: "Considerations related to synchronous Ethernet over 1000BASE-T and 10GBASE-T."

Recommendation G.8264: First released in 2008 and defines the Synchronization Status Message (SSM) protocol and formats for Synchronous Ethernet. It also defines the Ethernet Synchronization Messaging Channel (ESMC). More details on ESMC are described below. Corrigendum 1 was published in 2009 and contains changes related to Synchronous Ethernet. Amendment 2 consented February 2012 contains text to describe the use of Synchronous Ethernet with link aggregation.

Recommendation G.781: Released several decades ago and revised in 2008 to include Synchronous Ethernet. The new revision includes

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the definition of clock Quality Level (QL) values used for EEC-option 1 and EEC-option2 as well as the synchronization functions needed for Synchronous Ethernet equipment.

ITU-T Recommendation G.803 describes the overall SDH network synchronization architecture that uses PRCs, Synchronization Supply Units (SSUs) and SECs. Synchronous Ethernet was developed based on that same architecture. Figure 1 shows synchronization chains based upon Synchronous Ethernet and SDH NEs. Some equipment are hybrid nodes having both STM-N and Synchronous Ethernet interfaces as described in Appendix I of G.8262.

The Synchronous Ethernet interface can be configured in synchronous or non-synchronous mode. In non-synchronous mode it does not receive or transmit synchronization, does not process ESMC, does not participate in the synchronization network, and functions "asynchronously" as per IEEE 802.3. In Synchronous mode, it receives and transmits synchronization, processes ESMC, and participates in the synchronization network while still meeting all IEEE802.3 requirements.

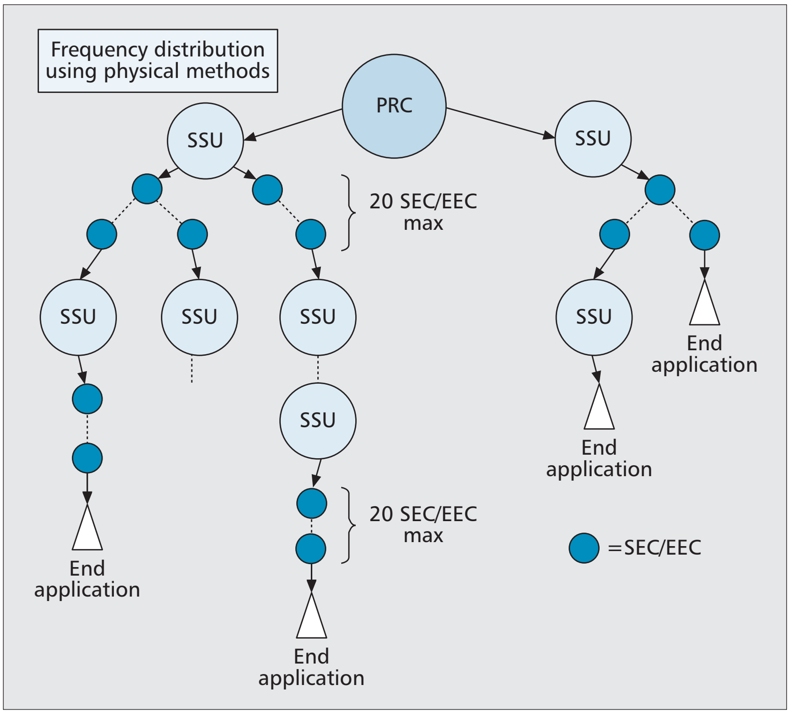

Figure 1. *Synchronization chains implemented with SECs and EECs.*

ESMC PROTOCOL

The ESMC protocol was developed to carry the SSM messages used by Synchronous Ethernet to exchange traceability information across a link. In SONET/SDH the SSM is carried in a fixed location within the frame header. With Synchronous Ethernet the SSM is carried by an Ethernet protocol based on the IEEE Organization Specific Slow Protocol (OSSP).

OSSP is a link protocol and the ESMC frame cannot be forwarded transparently by an Ethernet node. The ESMC must be terminated upon reception, and a new ESMC frame created for transmission to the next node.

SSM carries the quality level (QL) of the clock which is used for the synchronization selection process that is described in Recommendation G.781. The clock QL indicates the holdover performance of a particular clock type. The QL values for EEC-option 1 and EEC-option 2 were defined to be the same as G.813 Option 1 and G.813 Type IV (stratum 3), respectively. All other SSM codes used are as defined in G.781.

G.781 defines message processing times that are based on synchronization network reconfiguration requirements, and are related to the performance of SEC clocks for SONET/SDH and EEC clocks for Synchronous Ethernet. To meet these G.781 requirements, Synchronous Ethernet defines two types of ESMC message: heartbeat and event.

Heart-beat messages are used to continuously provide the clock quality level and are transmitted once per second. Event messages are used to convey a change in the SSM clock quality level and are generated and transmitted immediately upon detection of a clock quality level change. Five seconds without reception of an ESMC message causes the QL value to be considered as DNU (do not use).

Organizational Specific Slow Protocol (OSSP) — IEEE assigned ITU-T a Slow Protocol subtype, and an Organizational Unique Identifier (OUI) to be used by the ITU-T. The ITU-T then assigned an ITU-T subtype to identify the ESMC Protocol Data Unit (PDU).

In order to allow future enhancements and extensions to the protocol, ITU-T has designed the protocol to be structured with TLVs (Type Length Value) elements. The QL TLV is carried at a fixed location within the ESMC PDU. The event flag distinguishes the two types of the ESMC PDU frames.

Table 1 shows the ESMC PDU format.

ESMC Protocol Extensions — The ESMC protocol allows extension by means of defining new TLVs. One such extension is to carry phase and/or Time of day (ToD) by means of an IEEE-1588 timestamp inside a TLV. We will explore the use of a Timestamp TLV within the ESMC protocol.

DRIVERS FOR PHASE/TIME DISTRIBUTION BY THE NETWORK

Traditionally only accurate frequency synchronization has been required for proper operation of telecom networks. However, new synchronization requirements are emerging as part of the evolution of mobile networks where, in addition to a common frequency reference, a common accurate phase/time reference needs to be maintained between neighboring base stations. To meet some LTE (Long Term Evolution) radio interface requirements, a synchronization accuracy in the order of 1μs is required.

Examples of LTE features having phase/time requirement are: LTE Time Division Duplex, Multicast Broadcast Multimedia Services with Single Frequency Network (MBSFN), and Coordinated MultiPoint transmission and reception

Octet number	Size/bits	Field	Notes
1–6	6 octets	Destination Address = 01-80-C2-00-00-02 (hex)	IEEE-defined slow protocol multicast address (see Annex 43B of IEEE 802.3).
7–12	6 octets	Source Address	MAC address of the port that the ESMC PDU is transmitted
13–14	2 octets	Slow Protocol Ethertype = 88-09 (hex)	IEEE Slow protocol Ethertype
15	1 octet	Slow Protocol Subtype = 0A (hex)	Subtype assigned by IEEE to ITU, fixed value of 0x0A
16–18	3 octets	ITU-OUI = 00-19-A7 (hex)	IEEE registration authority assigned an Organizational Unique Identifier (OUI) to ITU
19–20	2 octets	ITU-T Subtype	ITU-T assigned a subtype value of 00-01 to be used by G.8264
21	bits 7:4	Version	Version of the ITU-T ESMC frame format
	bit 3	Event flag	A value of 1 indicates an event PDU; a value of 0 indicates an information PDU
	bits 2:0	Reserved	Reserved for future standardization
22–24	3 octets	Reserved	Reserved for future standardization
25–1532	4 octets	QL TLV	Data and padding necessary to achieve 64 bytes, it must be an integral number of octets
	32–1486 octets	Future enhancement TLVs and padding	
Last 4	4 octets	FCS	Frame check sequence

Table 1. *ESMC PDU format.*

(CoMP). The requirements applicable to these features can be found in [8] and [9].

The transport of a frequency reference in telecom networks can be achieved using the physical layer of SDH or Synchronous Ethernet. However, transporting an accurate phase/time reference over telecom networks is something new, and raises some challenges.

The only mature solution today to achieve very stringent phase synchronization (e.g. 1μs) is the Global Navigation Satellite Systems (GNSS) such as GPS (or Galileo in the future in Europe). Although providing very good timing quality, these GNSS solutions suffer from several drawbacks. First, the installation of antennas entails a certain cost. Moreover, it requires a direct view of the sky, which is not always available (e.g. indoor configurations). And finally, in the case of GPS, no guarantee of service is provided as part of the system. Since synchronization is critical to mobile networks, operators are reluctant to be completely dependent on GNSS systems. This provides the incentives for investigating alternative or complementary synchronization solutions to GNSS using the transport network.

Figure 2 depicts two scenarios: the first case shows a mobile network where GPS/Galileo receivers are located at the cell sites. The second case shows a mobile network where GPS/Galileo receivers are now located at the Central Office, leading to fewer receivers deployed. From the Central Office to the base stations phase/time distribution is achieved over a time capable network. "Time capable" implies that every node in the network is able to support the time protocol, which could be an existing protocol such as PTP or NTP or could be an extension of the ESMC channel, as described earlier. In both cases, it is suggested that frequency distribution from the network using physical methods (e.g. Synchronous Ethernet) could be used to aid and simplify phase/time distribution. The benefits of this scenario will be further detailed in the next sections.

Support from the Network for Phase/Time Distribution

The following sub-sections present the importance of having network support for accurate phase and time synchronization.

End-to-End Versus Link-By-Link Approach

Some time-of-day protocols like NTP are widely used to deliver time synchronization, but do not generally achieve 1μs accuracy. This is due to the "end-to-end" approach used. Timing packets are carried over the network without hardware support on the intermediate nodes, as illustrated in case 1 of Fig. 3. To achieve 1μs accuracy, it is likely that dedicated hardware support will be required in all the network nodes, as illustrated in case 2 of Fig. 3.

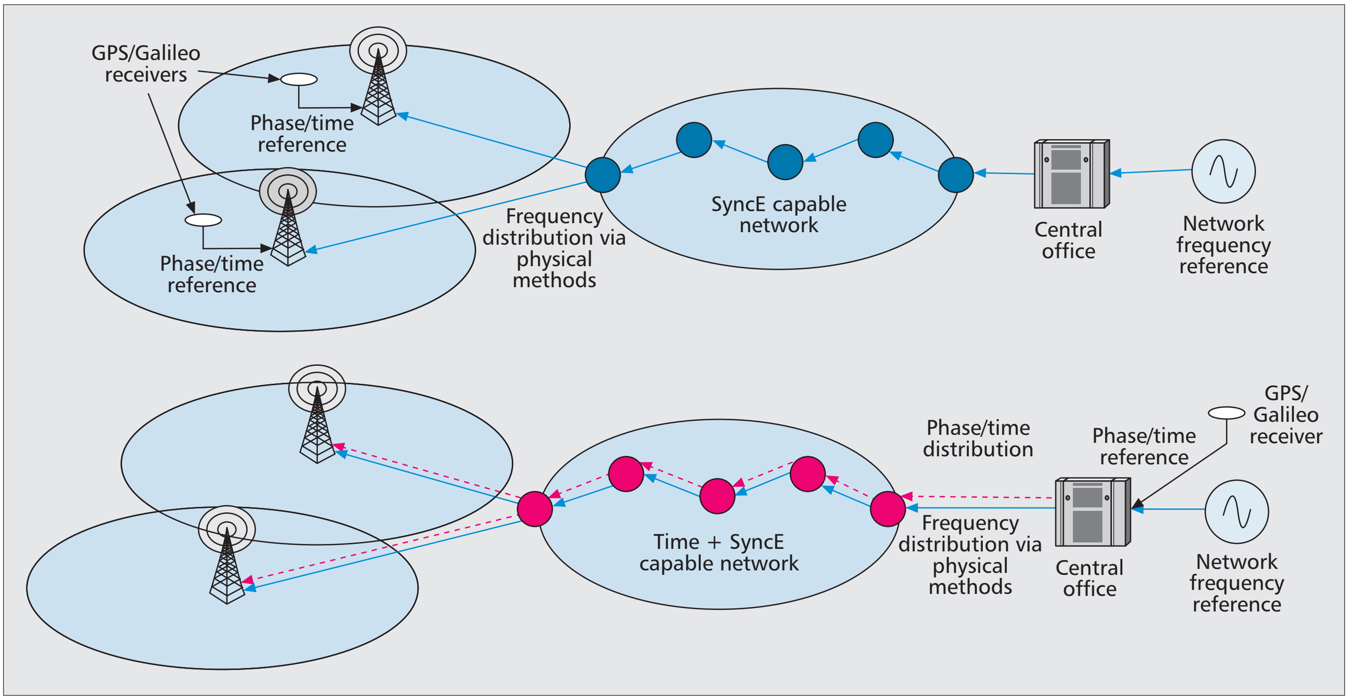

Figure 2. *Synchronization distribution by the network reduces the number of GNSS antennas.*

In an end-to-end approach, the timing flow is impacted by Packet Delay Variation (PDV) generated by the network. Each timing packet can be delayed differently in the queuing buffers of the nodes, creating different transit delays over the network. In general, a network produces PDV much higher than a few μs, which makes the "end-to-end" scheme inappropriate for meeting the requirements previously discussed.

Figure 4 provides an example of PDV produced by fiber-interconnected Ethernet nodes typical to mobile backhaul. As seen in Fig. 4, even when moderately loaded, significant delay steps exceeding 1μs are observed (beyond 50 percent loading results in more than 1μs of delay). Such delay steps could create delay asymmetry, and may exceed the 1μs accuracy requirement. From an operator perspective, ports loaded to less than half of capacity would make the network very inefficient! Note that this is an example of moderate PDV, and microwave or DSL links generally produce much higher PDV.

The only way to remove the PDV problem is to build a network with "hardware" support for timing in every node. This is true regardless of the protocol that transfers the timestamps. A link-by-link approach allows timing to be extracted and re-inserted, effectively by-passing the packet buffers, which are the main source of PDV. Legacy networks might not be able to support this.

The approach is similar to that of SONET/SDH, which requires all nodes of the synchronization path to support synchronization processing. New equipment could try to anticipate the need to support phase synchronization in hardware, which would then later allow deployed nodes to be field-upgraded with the appropriate feature.

Stable Frequency Support for Phase/Time via Synchronous Ethernet

It is recognized that having access to a stable and accurate source of frequency can help recover accurate phase/time.

Among the advantages of this "syntonization plus timestamp combination" are:

- Lower timestamp rate since the local clock is syntonized.
- Time holdover insures against longer breaks in the reception of the timing packets.
- Faster start-up and convergence of the phase/time reference.
- Reduced cost of the oscillator embedded in the equipment.

Note that the availability of stable frequency does not solve the problem of PDV on the timestamp messages. The link-by-link approach previously depicted is still required with both syntonization and timestamp processing in every node.

The noise accumulation of a chain of EECs needs to be further studied in order to support phase/time distribution. It is known that during rearrangement of the synchronization path, phase transients may happen. However, only the short-term noise accumulation on the frequency reference transported at the physical layer has to be considered when phase/time accuracy is concerned, since whenever timestamps are received, the accumulated phase error is corrected. Note that these aspects apply also when Synchronous Ethernet is combined with any time protocol.

ITU-T is studying the use of Boundary Clock (BC) to transport phase and time; a chain of Boundary Clocks will also accumulate noise. A Boundary Clock (BC) model has been developed by ITU-T and simulations have been run and are under study to determine the noise accumulation in a chain of BCs.

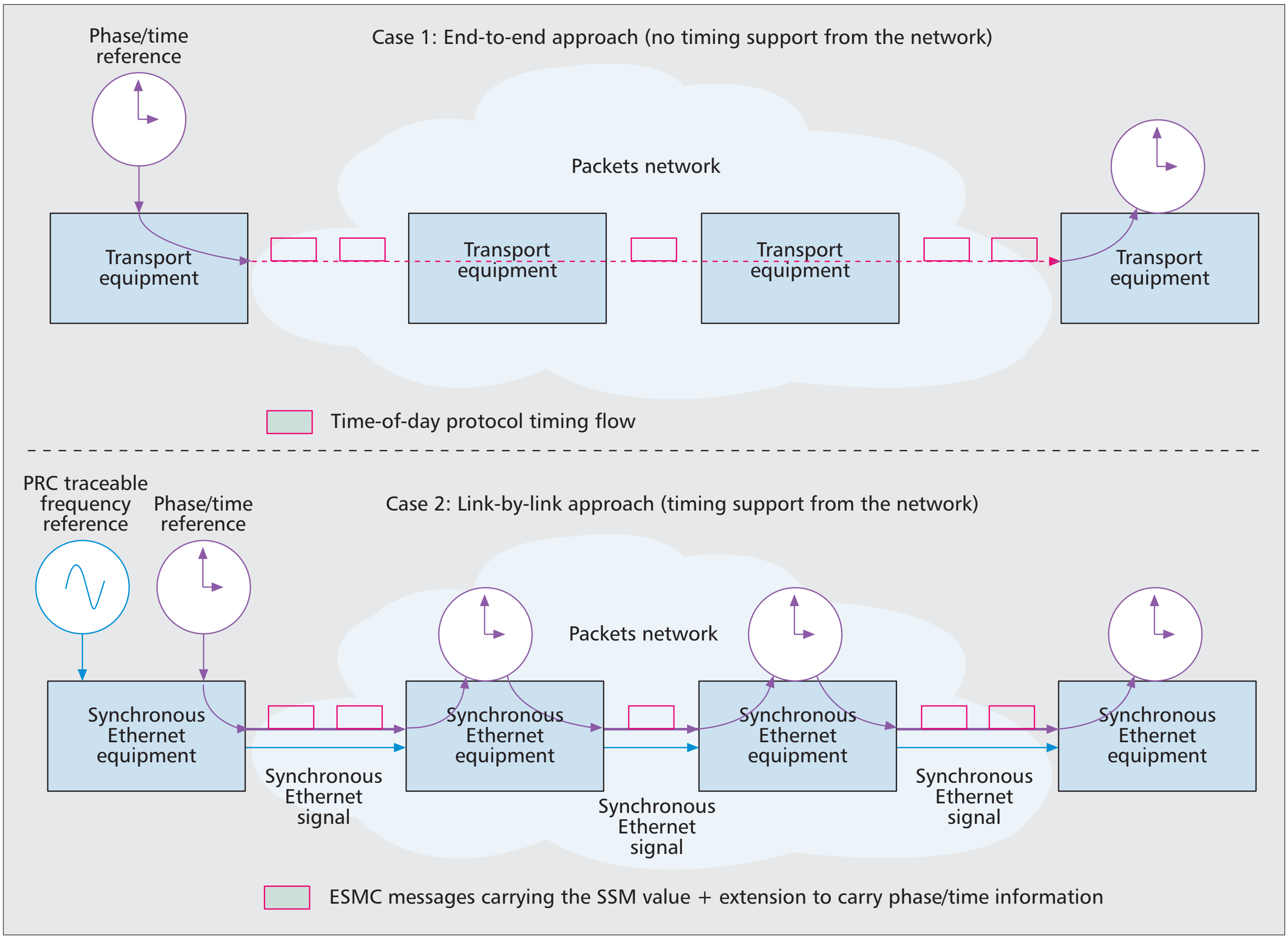

Figure 3. *End-to-end approach vs. link-by-link approach for phase/time distribution.*

The noise accumulation aspects of Synchronous Ethernet when used in conjunction with phase/time synchronization are being studied at the ITU-T.

Extending ESMC to Support Phase and Time

During the development of Synchronous Ethernet, several proposals have been made for extending the current specification of the ESMC allowing phase and time transport over Synchronous Ethernet, in addition to accurate frequency. This section will introduce the key concepts of such an extension, which is currently not part of the Synchronous Ethernet standards.

Rationale for Extending Synchronous Ethernet

The ESMC channel has been specified to ensure termination at every link; therefore this channel is suitable for transporting hop-by-hop the timing packets of a phase/time protocol. Timestamps sent in the ESMC will be delivered without store-and-forward queuing delays, as no queuing in interim equipment can take place on the fiber prior to reception and time-stamping at the far-end ingress port. Note that hop-by-hop phase/time transfer does not prevent timestamp accuracy errors; careful design is required to minimize these errors in any synchronization protocol (including PTP).

ESMC is based on a slow protocol, which limits the packet rate. However, in combination with physical layer frequency support it is expected that the low packet rate should still meet the targeted performance. This is still under study and simulations are needed to determine exactly the required regularity of the phase updates.

The SSM information carried with Synchronous Ethernet could also be useful for phase/time delivery. Phase/time synchronization distribution infrastructure could be built on top of the frequency distribution infrastructure, such that the existing network planning could be reused. Finally, equipment already deployed by an operator for frequency distribution, such as SSUs, might have a role to play in a synchronization network for phase/time distribution.

Implementation of TSE

Phase/time synchronization requires the transfer of timestamps and processing of the timestamps to compensate for transmission delay. Regardless of the protocol used, the slave needs to collect the four timestamps and calculate the clock offset using the formula:

Offset = ((T2 – T1) — (T4 – T3))/2.

By applying this offset the slave clock can synchronize to the time of the master clock. Symmetry of delays is assumed in the formula and any asymmetry needs to be compensated (e.g. via measurement).

Figure 5 shows an example of a TSE message exchange where a single ESMC message type is used, and compares it to the PTP message exchange. The nodes involved are directly connected across a link. To receive synchronization a node requires a slave function, and to propagate synchronization it requires a master function. Therefore, both functions would generally be implemented in a TSE capable node.

TSE aims at being very simple and at reusing the existing ESMC capabilities, i.e. enforced link-by-link forwarding and utilizing the QL TLV. The only addition required in the ESMC is a new Timestamp TLV (TS TLV) which would be used for transmitting phase/time information, as illustrated in Fig. 5. The functions could be implemented completely in hardware with little or no need for software intervention.

In order to allow for efficient implementation, the Timestamp TLV should always begin at a fixed location of the ESMC frame, e.g. directly following the QL TLV. A new flag "TS valid" could be defined in the header to indicate that a TS TLV is present and contains valid data.

In the case of multiple time sources the node could re-use the existing Synchronous Ethernet clock selection process based on G.781. This will be further explained in a later section. The direction of synchronization is implicit from provisioning, and the ESMC QL is used where direction of synchronization may change (e.g. in Ethernet rings) and further as a simple check to prevent timing loops. This again is in line with current synchronization practices.

Interfacing with PTP

The TSE mechanism has some high level similarities with IEEE1588 and can interface with PTP when needed. The following sections explain the main differences between TSE as it is proposed and PTP, and introduces briefly how they could interwork.

Comparison with IEEE1588

PTP is a highly capable time synchronization protocol that has different applications across diverse industries (e.g. test and measurements, industrial automation, and telecommunications) with multiple PTP profiles under development. TSE targets only telecom applications, and aims simply at adding the necessary features for phase/time synchronization over an existing tightly controlled frequency distribution hierarchy. For this narrow context, TSE can be seen as a simplified PTP solution.

For instance, TSE needs only one ESMC message type, while PTP defines nine message types of which two are shown in Table 2.

TSE provides equivalent high level functionality as a PTP Boundary Clock, in the sense that the phase/time reference is recovered by the node before being transmitted to the next node.

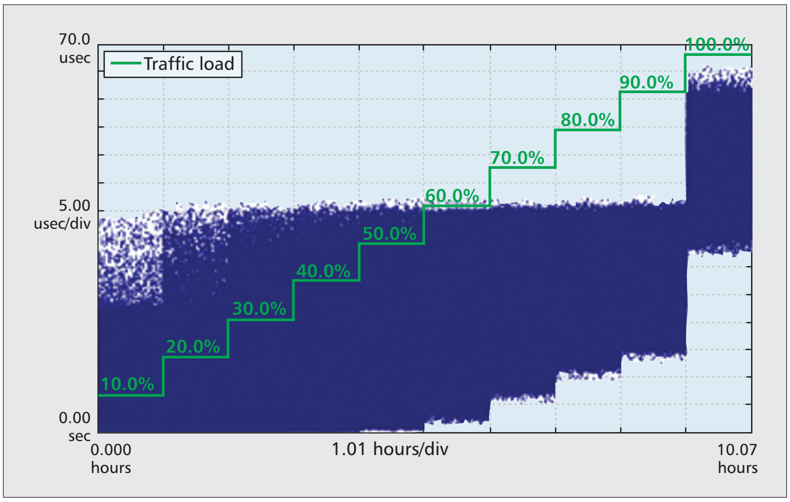

Figure 4. *Example of PDV produced by 2 Ethernet equipment.*

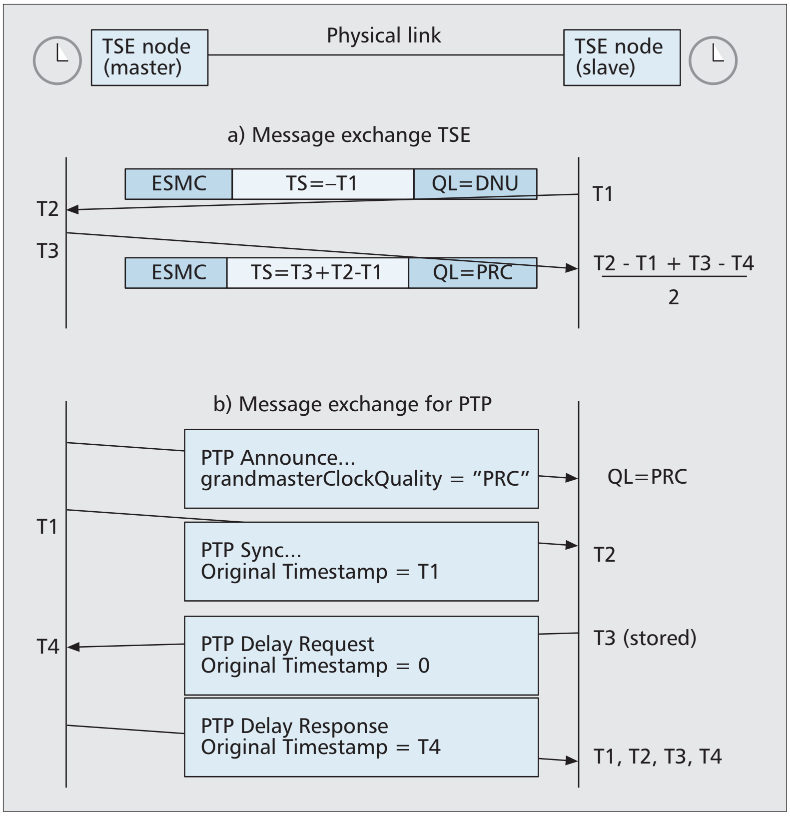

Figure 5. *Time synchronization between nodes using TSE and PTP.*

However, this does not imply support for all the protocol details associated with a PTP Boundary Clock, e.g. BMCA, data sets to be implemented and maintained, management, etc…

Using IEEE1588 hop-by-hop (e.g. with Boundary Clocks) combined with layer 1 frequency distribution (e.g. Synchronous Ethernet) can be considered as similar to TSE. However, additional complexity aside, it runs the risk of path separation, where the PTP packets follow a different route from the frequency delivered at the physical layer.

The adaption of PTP for delivery of accurate phase/time in a telecom environment is under

Comparison of PTP messages and Time Synchronous Ethernet messages

PTP Announce Message		Octets
Ethernet	Header	14
IP	Header	20
UDP	Header	8
PTP	Transport specific	1
	PTP version	1
	PTP messageLength	2
	domainNumber	1
	Reserved	1
	flagField	2
	correctionField	8
	Reserved	4
	sourcePortIdentity	10
	sequenceID	2
	controlField	1
	logMessageInterval	1
	Original Timestamp	10
	currentUtcOffset	2
	Reserved	1
	grandmasterPriority1	1
	grandmasterClockQuality	4
	grandmasterPriority2	1
	grandmasterIdentity	8
	stepsRemoved	2
	timeSource	1

TSE over ESMC		Octets
Ethernet	Header	14
	Slow protocol subtype = 0x0A	1
	ITU-OUI = 00-19-A7	3
	ITU-T subtype	2
	Flags:	1
	Version (bits 7-4)	-
	Event (bit 3)	-
	TS Valid (bit 2)	-
	Reserved (bits 1-0)	-
	Reserved	3
	QL TLV	4
	Timestamp TLV	14

PTP Sync Message		Octets
Ethernet	Header	14
IP	Header	20
UDP	Header	8
PTP	Transport Specific	1
	PTP version	1
	PTP messageLength	2
	domainNumber	1
	Reserved	1
	flagField	2
	correctionField	8
	Reserved	4
	sourcePortIdentity	10
	sequenceID	2
	controlField	1
	logMessageInterval	1
	Original Timestamp	10

Timestamp TLV	Octets
Type: 0x02	1
Length 0x00 0E	2
Timestamp seconds	6
Timestamp nanoseconds	4
Reserved	1

Table 2. *Comparison of PTP messages and Time Synchronous Ethernet messages.*

study at the ITU-T. A significant part of this work is the development of a PTPv2 telecom profile for phase/time. By comparison, TSE requires defining a new TLV for the ESMC and specification of TLV processing rules.

Statically Provisioned Synchronization Network Versus Self-Provisioning

Timing distribution in telecoms has traditionally been based on static provisioning, based on a study of the network architecture.

For instance, in physical based frequency delivery, the network topology is analyzed in order to determine a timing distribution architecture, which avoids timing loops, and complies with engineering rules specified in standards (such as ITU-T Rec. G.803).

Static provisioning does not preclude automated handling of failure cases: the timing distribution is generally secured, for instance via synchronization path diversity, and specific mechanisms such as the SSM can be used to automatically reconfigure the network in case of failure. However, these mechanisms assume that the potential failure events have been studied

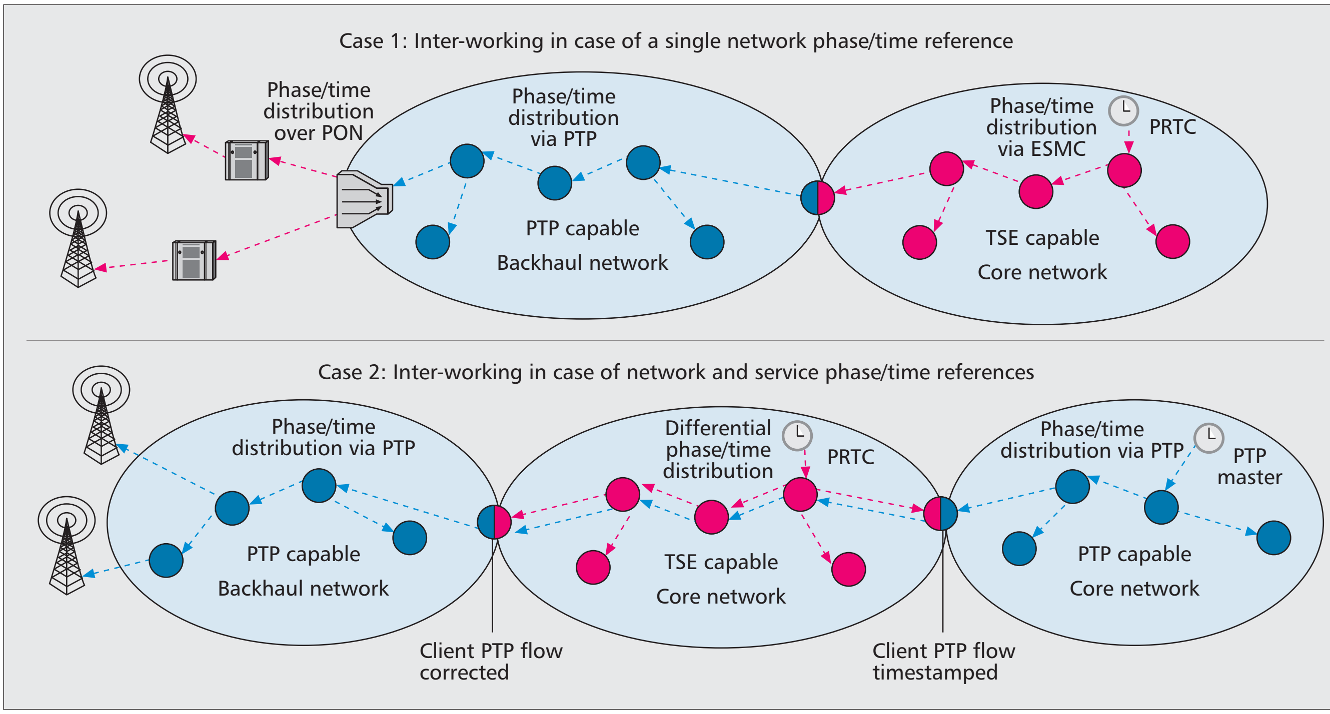

Figure 6. *Distribution of phase or time using network native synchronization capabilities.*

during the network planning phase (poor analysis can lead to timing loops in case of failure).

Traditional synchronization network planning and protection mechanisms do not rely on protocols in order to automatically determine the timing distribution topology. The default Best Master Clock Algorithm of IEEE1588, where the nodes of the network organize automatically into a master-slave hierarchy via the exchange of PTP messages, is still not familiar in telecom networks.

Static provisioning is important, as it allows network operators to have full control of their timing distribution. Failures are in general not very frequent; therefore the timing distribution does not change very often. An efficient supervision system is key for managing failure events in a synchronization network. Continuing to allow static provisioning for phase/time synchronization distribution is considered important.

Interworking with PTP and Other Phase/Time Distribution Mechanisms

TSE offers a technology-specific mechanism for transporting a network phase/time reference over Ethernet transport networks. This mechanism can interwork with other phase/time distribution mechanisms, such as IEEE1588.

Passive Optical Networks (PONs) offer a mechanism for accurate phase/time synchronization highly coupled to the transport technology. A ranging mechanism is specified in this technology to compensate for propagation delays, therefore PON equipment are phase-aligned. This ranging mechanism has been recently extended to transmit a timestamp with time information. Some studies are also on-going for enhancing DSL technologies with an equivalent mechanism.

Case 1 of Fig. 6 illustrates a possible interworking scenario where a single network phase/time reference is delivered over the network to the end equipment. The phase/time reference is delivered from a Primary Reference Time Clock (PRTC) over a core network down to a PTP-capable backhaul network. This reference provided by TSE is then transported over the backhaul network via PTP down to a PON system. Finally, the PON system delivers this phase/time reference to the end application using its native mechanism via an appropriate phase/time interface.

Case 2 of Fig. 6 illustrates another possible interworking scenario where a service phase/time reference, provided by a PTP master, is transported over a TSE network that is synchronized by a different time reference. Borrowing the concepts of network clock and service clock from frequency distribution, we can consider that TSE has "network time" and the PTP network has "service time". So in this example PTP is using the TSE network both for transport of data and service time. Service time can be transported across the TSE network with high accuracy being corrected for packet delay variation.

For instance, the difference between the two clocks can be encoded and transported over the TSE network so that at the PSE egress, the original service time reference can be recovered. Alternatively, the time spent by each PTP packet traversing the TSE network can be compensated. This concept is similar to the residence time calculation performed by a Transparent Clock as specified in PTP, but calculated over a network instead of a single node. Using such principles, it is possible to carry as many different instances of service time as are needed over a TSE network, e.g. multiple service operators using the

Synchronous Ethernet can help in meeting evolving LTE mobile network requirements for phase/time synchronization, by providing stable and accurate frequency distribution. The ESMC channel of Synchronous Ethernet can be extended to support phase and time distribution.

same transport operator's network. Other interworking scenarios are also possible. In general, it is expected that different mechanisms, including PTP, will have to interwork with each other.

CONCLUSION

Synchronous Ethernet is a mature technology for frequency distribution, which has been fully standardized in ITU-T based on an initiative from operators. It enables straightforward interworking with traditional synchronization networks (e.g. SDH), since it is based on the same principles. This mechanism provides excellent frequency distribution quality, is widely supported within the telecom industry, and can be considered a low cost solution when designed into the equipment.

Synchronous Ethernet can help in meeting evolving LTE mobile network requirements for phase/time synchronization, by providing stable and accurate frequency distribution. The ESMC channel of Synchronous Ethernet can be extended to support phase and time distribution, using the TSE mechanism presented in this article. This extension to ESMC has been proposed to the ITU-T.

REFERENCES

[1] J. L. Ferrant *et al.*, "Synchronous Ethernet: A Method to Transport Synchronization," *IEEE Commun. Mag.*, Sept. 2008.

[2] ITU-T G.8261, "Timing and Synchronization Aspects in Packet Networks," Apr. 2008.

[3] ITU-T G.8262, "Timing Characteristics of Synchronous Ethernet Equipment Slave Clock (EEC)," Aug. 2007.

[4] ITU-T G.8264, "Distribution of Timing Through Packet Networks," Oct. 2008.

[5] ITU-T G.781, "Synchronization Layer Functions," Sept. 2008.

[6] ITU-T G.803, "Architecture of Transport Networks based on the Synchronous Digital Hierarchy (SDH)."

[7] IEEE Std 1588™-2008 "IEEE Standard for A Precision Clock Synchronization Protocol for Networked Measurement and Control Systems," July 2008

[8] J. L. Ferrant *et al.*, "Development of the First IEEE 1588 Telecom Profile to Address Mobile Backhaul Needs," *IEEE Commun. Mag.*, Oct. 2010.

[9] A. Magee "Synchronization in Next-Generation Mobile Backhaul Networks," *IEEE Commun. Mag.*, Oct. 2010.

BIOGRAPHIES

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