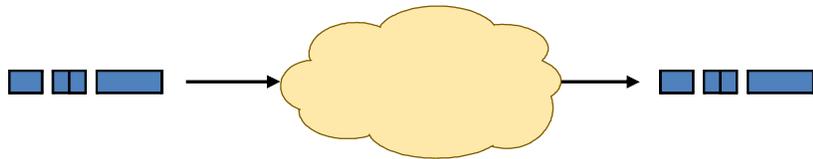# TransPacket white paper

Synchronization and precise timing in packet networks

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Supporting mobile back-haul and real-time applications

Executive summary

IP/MPLS and Ethernet packet optical networks are now a widely deployed technology and are being applied in all network segments and should therefore be able to support all types of network applications. Replacing the circuit switched synchronous SDH/SONET networks does however represent a number of challenges, where delay and synchronization are among the most prominent. E.g. mobile networks have strict requirements to accuracy of both frequency and time references. In synchronous networks this is solved using inherent synchronization mechanism of the network. In packet networks however, delay becomes unpredictable because of the asynchronous nature of these networks. Depending on the specific application, mechanisms and several standards and variants of standards exist for supporting the different synchronization requirements in packet networks. Rather than solving the timing problem for specific applications, a network should be designed more general, being able to support both current as well as future network applications. TransPacket brings a general and future proof solution to the delay

and synchronization problem in packet networks through its novel fusion network technology (also called integrated hybrid network). The technology is based on Ethernet packet transport, but as for the synchronous SDH/SONET circuit networks, transport is fully predictable, enabling synchronization and zero packet loss. The technology is still fully compatible with Ethernet, with the throughput and cost efficiency known from the packet networks.

This whitepaper gives an overview of synchronization and delay requirements for a selection of applications. In light of this, the implications on the network design and requirements to equipment are discussed. We then explain the basics of mechanisms that typically are applied in pure packet networks, synchronous Ethernet (SyncE) which is physical layer (L1) based, and the Precision Time Protocol (PTP, IEEE 1588, G.8265) which relies on packet layer synchronization. We then show how TransPacket brings a more general and future proof solution with the fusion network technique, meeting synchronization and stringent timing challenges as well as other future challenges related to supporting circuit properties in packet optical networks.

Synchronization and precise timing in packet networks
SUPPORTING MOBILE BACK-HAUL AND REAL-TIME APPLICATIONS

Synchronization requirements for packet networks

The current prime driver for synchronization in packet optical networks stems from the requirements of time and frequency references to mobile base stations. Mobile base-stations require an accurate frequency reference for generating a radio-signal at the output of the base-station with both long-term frequency accuracy and short-term stability. The accurate time-reference on the other hand, gives an exact time-of-day reference and is needed for supporting the correct generation of the signals on the radio interface. This is for ensuring precise handover between base-stations. For e.g. LTE systems, the required precision on the time-reference depends on the size of the cells, with the highest accuracy required for the smallest cells.

Other examples of services benefiting from precise time synchronization in the networks are circuit emulation services (CES), precise time-of-day dissemination, precise latency measurements, Digital Video Broadcast (DVB-T/H) and a number of industrial applications. Table 1 lists the tolerance to timing variations of different types of applications. As can be seen from the table there are examples of applications, e.g. digital video broadcast, that have even stricter demands to frequency and time accuracy than the mobile backhaul networks. The required accuracy is however within the same order of magnitude as for the mobile systems, with microsecond accuracy for the time-reference and 0.05 ppm accuracy for the frequency.

Application	Time/phase accuracy	Frequency accuracy
Mobile systems: 3 GPP2, (LTE, TD-SCDMA, CDMA 2000)	3 micro-seconds	+/- 0.05 ppm
WIMAX	+/- 0.5 to 5 Micro-seconds	+/- 2 ppm
DVB-T/H	1 Micro-seconds	Few ppb
Automation	Milliseconds	
Motion control (robotics)	Millisecond	
Synchrophasor measurement	Micro-seconds	
Electronic ranging	Sub Micro-seconds	

Table 1, time and frequency accuracy requirements for a range of services.

The need for synchronization support in operator networks

The strict requirements for time and frequency references are well known in mobile back-haul network design. However a number of operators do not have mobile services or similar time/frequency reference demanding services within their own business portfolio. Still, these demands may be a requirement from the customers of these operators. An example is illustrated in figure 1 where a fiber-infrastructure operator is offering a broad range of transport-services. The figure illustrates simultaneous transport of both mobile-services and broadcast-services through the network of the fiber-infrastructure operator. Since transport of the customer signals requires transport of references for both frequency and time, the demands listed in table 1 apply for the fiber-infrastructure operator as well as for the customers of the operator. Hence, operators offering transport-services should include requirements from the mentioned applications into consideration when planning and deploying networks. Since transport of such signals may involve both the access/metro as well as the transport-network, techniques for supporting the mentioned demands should be implemented in all network-segments.
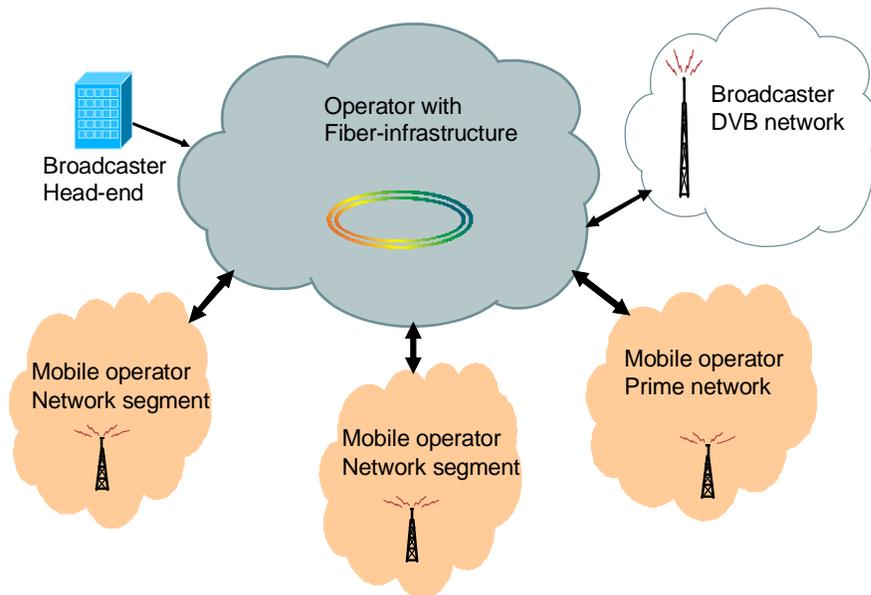
Figure 1, Operator with fiber-infrastructure offering transport services to mobile operators and a broadcaster.

Synchronization techniques

Traditionally, the timing reference has been carried at the networks physical layer. SONET/SDH and Plesiochronous Digital Hierarchy (PDH) have native capability to carry a timing reference. With the migration to Ethernet, distribution of synchronization is however not a native property and has become a challenge. This is because Ethernet was not built for distributing synchronization. In difference from SONET/SDH/PDH networks, frequency distribution is not mandatory for Ethernet networks, because the network works without timing synchronization.

One method for achieving local synchronization and accurate time-of-day information in a network is through using Global Positioning System (GPS) receivers. In e.g. a mobile system, a GPS receiver may be installed at every mobile station, ensuring proper synchronization. Using GPS does however have some drawbacks:

1) A GPS receiver antenna requires free line-of-sight to the GPS satellites, complicating installation. The trend is that density of base-station deployment is growing and optimizing the location of the base-station with respect to GPS reception therefore becomes increasingly difficult. Furthermore, deployment of in-door base stations will require installation of an out-door GPS antenna, complicating the installation and increasing the cost.
2) The GPS receiver represents an added cost. GPS receivers with the accuracy needed for precise synchronization is expensive.
3) The GPS system may be switched off in case of extraordinary military activities.

Distributing synchronization through the network overcomes these drawbacks and ensures a cost-effective and easy-to-deploy solution.

Standards for synchronization in packet networks

There are two main techniques applied for achieving synchronization in packet networks, the Ethernet physical layer based SyncE and the packet layer based Precision Time Protocol (PTP). The PTP is also known as IEEE 1588 [1]. Several versions and drafts exist of this standard. IEEE-1588 (2008) is defined for networked measurement and control systems. This protocol was adopted and further defined by the ITU-T for deployment in Telecom networks. The ITU-T G8265.1 [2] recommendation describes the deployment of IEEE-1588v2 in telecom networks for supporting the required timing precision and transfer of frequency. Also another variant based on IEEE-1588v2 for synchronization of Audio/Video bridging (AVB) networks exists, IEEE 802.1AS [3]. This standard specifies requirements to allow for transport of precise timing and synchronization in AVB networks. SyncE is standardized by ITU-T. The standards G.8261 [4], G.8262 [5] and G. 8264 [6] describe the SyncE framework, accuracy requirements and deployment in the network.

PTP versus SyncE

A general structure applied for distributing synchronization information in packet network is illustrated in figure 2. A master clock based on information from a Global Positioning System (GPS) unit is applied as a reference clock for the network. Clock information is then distributed through the network to several slave units.
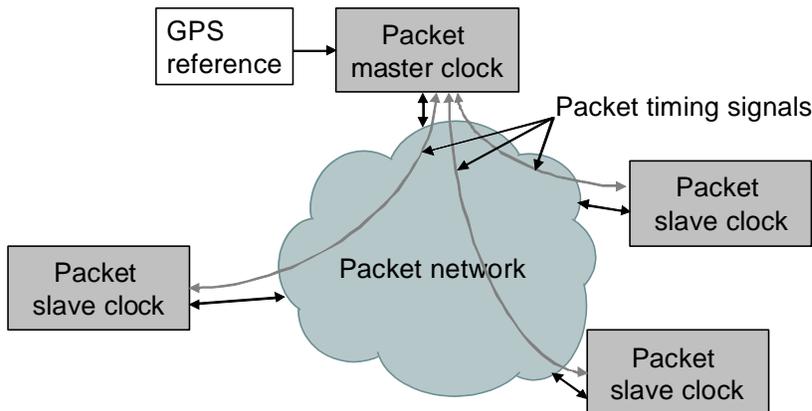

Figure 2, a general structure for distributing synchronization in packet networks. If deploying SyncE, every node in the packet network must support SyncE.

The SyncE relies on techniques well known from SDH/SONET systems, distributing a frequency on the physical Ethernet layer from a primary reference source (PRC). The PRC typically relies on a signal from a GPS unit. Since synchronization is provided on the physical layer, implementing SyncE in the network relies on support of SyncE in every node along the synchronization path. The SyncE frequency reference is applicable both as a frequency reference for generating a precise radio frequency and as a relative time reference for time-of-day applications. It does however not carry the time-of-day information (wall clock, absolute time).

In contrast to SyncE, the PTP protocols do carry information about time-of-day. Also this technique relies on synchronizing slave clocks according to a master clock, as illustrated in figure 2. However, the main difference is the transmission of synchronization information at the packet layer rather than at the physical layer as for SyncE. The principle is illustrated in figure 3. Special PTP packets containing time-stamps are sent both directions through the network. Using this technique, a round-trip time is calculated from the mean delay measured for each of the directions through the network.
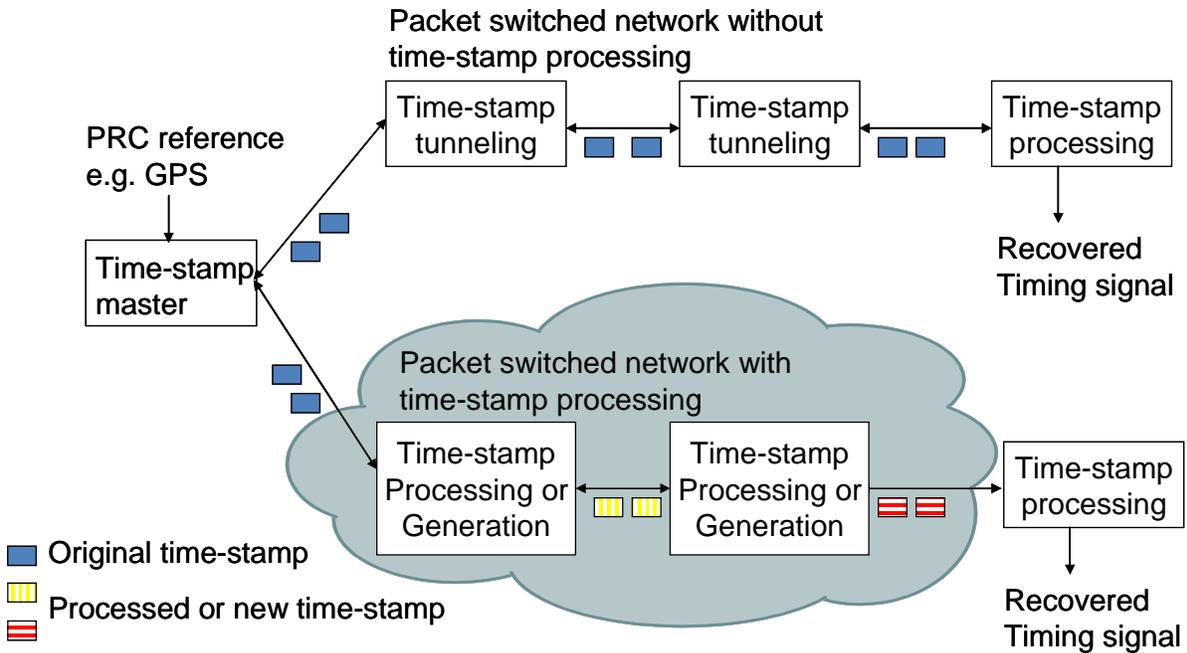

Figure 3, Time-stamping of packets is applied for measuring delay through the network. A time-stamp master works as a Primary Reference Clock (PRC) using a GPS as the reference. Time-stamp packets are generated and sent into the network. Processes at the far-end of the network recover the timing signal. The network may either be tunneling the time-stamps through the network without processing (upper figure), or process time-stamps in every node (transparent clock) adding a correction value corresponding to the delay through the node (lower figure). Alternatively the node can process the in-bound time-stamp and generate a new out-bound time-stamp. In both the latter cases, all nodes must implement the PTP.

While SyncE provides both a precise frequency and relative timing reference, PTP first of all provides a time-of-day reference. PTP may also provide a frequency and relative time reference, but meeting the accuracy demands for e.g. mobile backhaul using PTP is very demanding [7]. A second difference from SyncE, is that PTP in principle can be implemented only in the PRC reference node and in the end-node requiring the synchronization signal, e.g. the mobile base-station. PTP packets are then tunneled through the packet switched network as shown in the upper part of figure 3. In practical implementations this may however be difficult because the accuracy of the PTP protocol depends on the transport properties of the PTP packets through the network. Firstly, any difference in delay between the path and return path between a master and slave clock impacts accuracy [8]. Secondly, variations in packet delay along the path, i.e. packet delay variation (PDV), also impacts accuracy. Hence, any Packet Delay Variation (PDV) or

asymmetry in delay imposed on PTP packets should be avoided. If support of the PTP protocol is implemented in all the switches or routers along the PTP path in the network (lower part of figure 3), PDV on PTP packets is compensated, and high precision can be achieved. Experiments have shown that using PTP for synchronization purposes in packet networks may be a viable approach [8]. However, in the experiment, the clock was regenerated at every intermediate node and support of time-stamping was implemented in the Media Access Control (MAC) layer of all intermediate switches.

A typical question that may be asked is if the packet network should support SyncE or PTP. For the reasons outlined above, achieving both the required exact frequency reference and the exact time-of-day reference, both the SyncE and the PTP protocol may be implemented in the network [7].

Applying PTP in networks with switches not supporting PTP

In a great majority of deployed packet switched networks, the switches do not support PTP. Hence, PDV and asymmetry in delay are imposed on all packets in the network. This is because switches and routers apply the "store and forward" principle, involving buffering of all packets before being forwarded. All packets arriving at the input interfaces are typically buffered into one output queue for each output interface. Contention occurs when two or more packets destined for the same output arrives simultaneously at different inputs. The simultaneously arriving packets are then first buffered in the output queue, and then scheduled out from the output one-by-one. This result in packets undergoing different delays through the switch or router, hence PDV occurs. As an example, if two packets of 1500 Bytes length arrives simultaneously to a switch and are destined for the same 10 Gb/s output-link, one of the packets must be delayed corresponding to at least the duration of a packet being scheduled. This corresponds to 1.2 microseconds, and hence a PDV of at least 1.2 microseconds may occur in every switch along the path. Applications requiring very high precision, like e.g. the mobile networks with its 3 microsecond accuracy demands, rely on much smaller PDV than is typically achievable in these packet switched networks. Hence, a guarantee of the required precision is hard or even impossible to achieve in these networks.

Transparent transport in fusion networks

TransPacket fusion networking supports syncE and provides transparent packet loss free transport with minimum delay and PDV of any type of packets, also any PTP or similar type of packets. The benefits of the TransPacket solution compared to other packet switch solutions are:

1) PTP type of protocols may only be implemented in the PRC node and the end-nodes where the synchronization is needed, like e.g. in a mobile base-station. Nodes along the transport path are transparent and tunnels through any type of packets, also PTP, with minimum PDV.
2) A protocol independent and future proof transport solution. Rather than a full upgrade of all nodes in the network, support of any future PTP or similar protocol-standards does not require upgrade of the transport equipment, but only the PRC node and end-nodes.
3) Ultimate performance for real-time applications like e.g. financial applications and robotics. A predictable ultra-low delay through the network is achieved through avoiding the use of the store-

and-forward mechanism in the nodes. Be aware that PTP and SyncE are mechanisms for achieving synchronization and does not decrease the delay through the network.
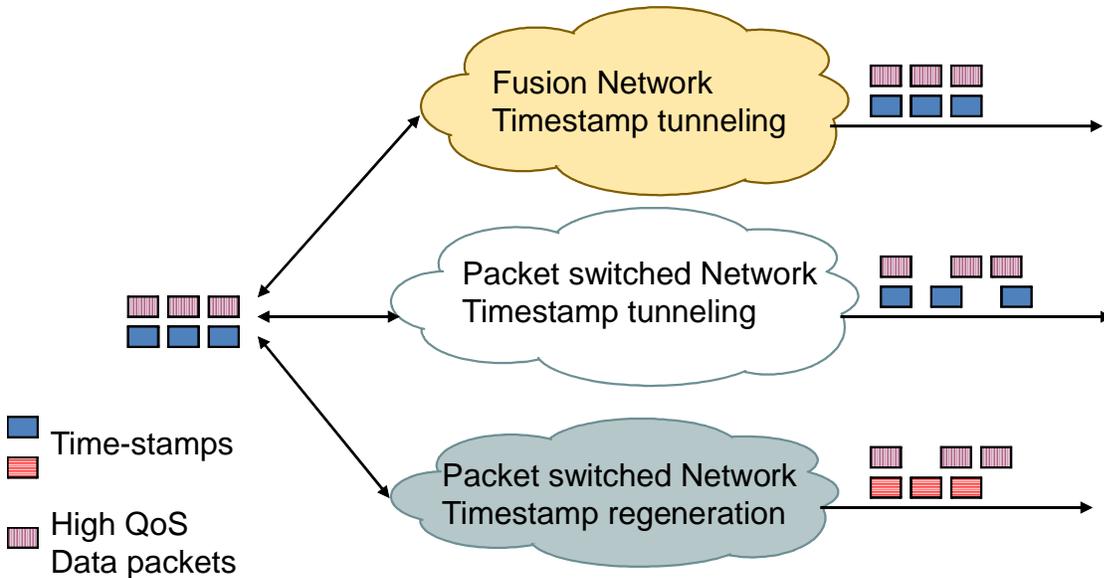

Figure 4, Comparison of data-packet and time-stamp transfer through 1) a fusion network 2) a packet switched network and 3) a packet switched network with PTP time-stamp regeneration in all nodes. The fusion network minimizes delay and PDV on any type of packets.

These benefits are achieved using TransPackets fusion networking nodes, enabling a unique combination of properties from packet switching and circuit switching. Unique properties are achieved with a transparent transport with no packet loss, ultra-low delay, and PDV in the nano-second range. TransPacket nodes use transparent Ethernet lines, a virtual wavelength functionality providing wavelength-grade quality of service. In difference from a wavelength (which is pure circuit switched), granularity is higher and typically several transparent Ethernet lines are provided within one wavelength. Furthermore, the fusion network approach allows statistical multiplexing of packets in-between circuit-switched packets following a transparent Ethernet line. This enables the simultaneous achievement of unbeatable low delay and PDV and the high throughput efficiency well known from packet switched Ethernet networks. More information on TransPacket fusion network principle can be found in the TransPacket "Introduction to fusion networks" white paper.

Summary

While operators offering mobile services always need to design the network for supporting stringent timing characteristics, all operators offering transport services should consider how timing-critical services and synchronization transport can be supported by their network. Operators offering transport services based on SDH/SONET have native support of synchronization. Circuit switched SONET/SDH networks are steadily being replaced by packet networks. Different from the circuit switched networks, packet networks do not natively support synchronization. Still the need for services offering synchronization and critical timing

remains. Mobile back-haul networks are a prominent example of a network with synchronization needs in a growing market, but a number of other applications like e.g. digital video broadcast, automation and robotics also benefits from networks with precise timing characteristics. When deploying a packet network it should be able to support all applications, current as well as future needs should be kept in mind. A unique and more general and future proof transport solution is available from TransPacket with the timing characteristics from circuit networks combined with the throughput efficiency of packet networks. TransPacket products offers transparent tunneling of packets through the network with no packet loss, adding a minimum of delay and packet delay variation. Hence, the TransPacket solution supports both current and future PTP (1588) type of protocols as well as other current and future applications with stringent timing requirements, without the need for future upgrade of network elements. This is in contrast to a to a pure packet switched network where the PTP protocol support may be required in every network element along the transport-path and real-time critical applications are difficult or impossible to support. Two main techniques for synchronization are being deployed in packet networks, SyncE which is physical layer based, and PTP which relies on synchronization at the packet layer. Accuracy of PTP strongly depends on the transmission characteristics through the network; Packet delay variation must be minimized or PTP time-stamp processing must be supported in every node. Typically deployment of both SyncE and PTP is preferred since SyncE enable a precise frequency reference and PTP enables a precise time-of-day reference.

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