

# Synchronization & Mobile networks

## 1. INTRODUCTION

For many years the frequency synchronization requirements of GSM, 3G and UMTS networks were satisfied by means of TDM signals such as T1 or E1. This solution was straight forward because the infrastructure to support mobile backhaul was made of SONET / SDH, thereby the synchronization signal could be extracted from the PHY layer or being transported through a separate network. In any case both transport and synchronization were based on TDM technologies.

### From Circuit to Packet migration

However, during the last decade many things have changed, mainly because mobile operators have been abandoning SONET/SDH circuits while adopting Ethernet / MPLS / IP to support new mobile backhaul architectures. This is a major challenge for base stations that always require a very accurate synchronization that native Ethernet can't supply.

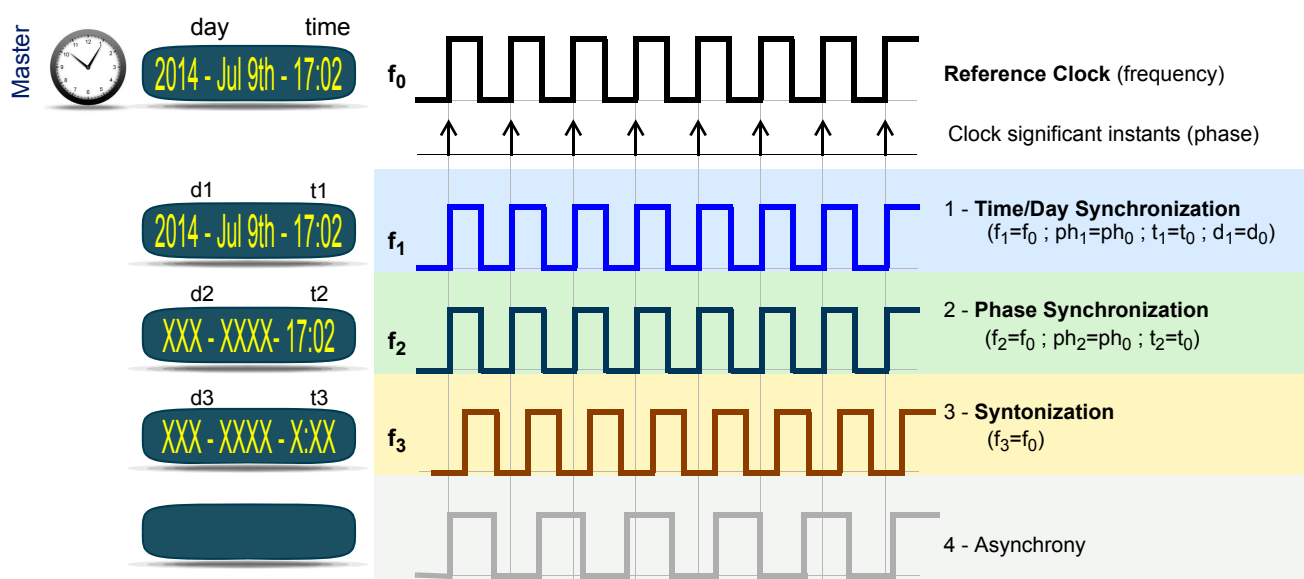


Figure 1 Synchronization of Frequency and Phase error of a signal in relation to its Reference Clock.

## Why Synchronization is required?

Synchronization enables many services including assisted navigation, location, and emergency calls. Moreover, synchronization is fundamental to every cellular technology otherwise they would not even work. Base stations must calculate permanently the distance to every single mobile operating in their cell and the neighboring cells. Base station and mobiles have to generate exactly the up/down frequencies and have to access to transmission time-slots. There are many reasons to keep a good synchronization:

- to calculate the distance to mobile terminals,
- to support geographical localization services,
- to control the transmission power,
- to avoid interferences with other cells and base stations,
- to manage handovers,
- to get accurate access to the time-slots,
- to compensate the propagation delay,
- to reuse frequencies efficiently,
- to plan small and micro cells,
- to calculate the billing.

Then we agree that synchronization is fundamental for any basic mobile service therefore it is just impossible to get rid of it.

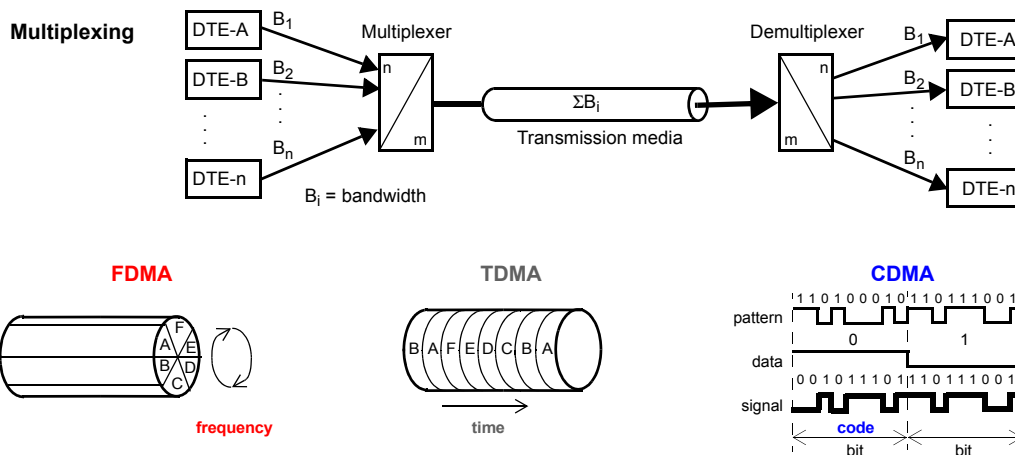
## Some background in multiplexing & synchronization

### Multiplexing and Multiple Access

Multiplexing is defined as the process by which several signals from different channels share a channel with greater capacity. Basically, a number of channels share a common transmission medium with the aim of reducing costs



**Figure 2** *Ether.Genius* is an multitechnology tester equipped with all the features to install and troubleshoot networks based on Gigabit Ethernet, Synch Ethernet, Precision Time Protocol and E1. **Net.Storm** it is a compact WAN emulator. Bandwidth control is done by means of Traffic Shaping & Policing impairments (delay, loss, jitter...), are inserted in a 100% controlled way. **Net.Hunter** is a stream-to-disk appliance capable of monitoring live traffic to capture selected TCP/IP flows at wirespeed.



**Figure 3** Multiplexing consolidates lower capacity channels into a higher channel. Frequency division multiplexing (FDMA). Time division multiplexing (TDMA) and Code division multiplexing (CDMA).

and complexity in the network. When the sharing is carried out with respect to a remote resource, such as a satellite, this is referred to as multiple access rather than multiplexing (see Figure 3). Some multiplexing technologies are:

- **Frequency multiple access (FDMA):** Assigns a portion of the total bandwidth to each of the channels.
- **Time division multiple access (TDMA):** Assigns all the transport capacity sequentially to each of the channels.
- **Code-division multiplexing access (CDMA)** air interface facilitates multiple access over a channel using spread-spectrum with a code per transmitter
- **Polarization division multiple access (PDMA):** polarization direction can be used as a multiple access technique in installations that use microwaves.
- **Space division multiple access (SDMA):** using directional antennas the same frequency can be reused, provided the antennas are correctly adjusted.

### Duplexing

Base stations use today three two technologies to multiplex upstream and downstream channels: frequency division duplexing (FDD), time division duplexing (TDD) and code division multiplexing (CDM).

- **FDD base stations** air interface uses separate frequencies for the up/down-link, then requires only a frequency synchronization.
- **TDD base stations** air interface uses the same frequency for the up/down-link then an absolute time and phase reference is required to get access to time slots (see Figure 4).
- Synchronization and Synchronization
- Are similar concepts but not exactly the same:
- **Synchronization** is the alignment of clocks to the same frequency, as SDH/SONET used to do

- **Synchronization** is the alignment of clocks to the same frequency and to the same phase
- **Time of day synchronization**, is the alignment of clocks to the same frequency, to the same phase and to a time origin. Then all clocks are aware of the time and date information.

## 2. ALTERNATIVES FOR TIMING

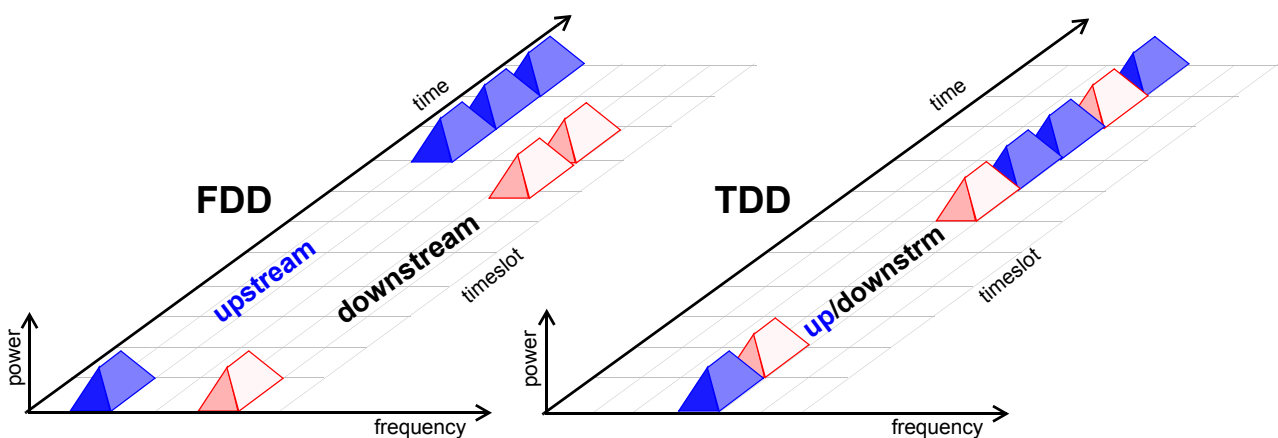
Once mobile backhaul has been migrated to Ethernet/ IP / MPLS there are a number of alternatives to get the synchronization. The first one is to maintain the TDM signal however it is an expensive option. The second alternative is GPS or GLONASS that can provide an absolute time reference. Finally SyncE and PTP facilitates are the third alternative and are based on the provision of timing through the packet network. This is probably the most interesting for new mobile networks and it is cost-effective solution.

The truth is that many are replacing TDM lines with Synchronous Ethernet and packet clocks using IEEE1588v2. Both SyncE and IEEE1588v2 are additions to the Ethernet data network, and provide the timing service to the mobile networks. Backhaul networks already require synchronization, and as this trend is continuing to include synchronization.

### Synchronization with TDM

There is a number of TDM signals that are suitable to be used as timing-source:

- Analog: 1,544 and 2,048 kHz;
- Digital: 1,544 kbit/s (T1) and 2,048 (E1) kbit/s;



**Figure 4** In FDD duplexing upstream and downstream use separate frequencies, in TDD upstream and downstream share the same frequency. FDD requires only syntonization while TDD is more and efficient on the use of the available bandwidth but requires Phase Synchronization.

- STM-n/OC-m line codes: from which one of the above-mentioned signals can be derived, by means of a specialized circuit.

The employment of STM-n/OC-m signals has the advantage of using the S1 byte to enable synchronization status messages (SSMs) to indicate the performance of the clock with which the signal was generated. These messages are essential in reconstructing the synchronization network automatically in case of failure. They enable the clocks to choose the best possible reference, and, if none is available that offers the performance required, they enter the holdover state.

### GPS or GLONASS synchronization

GPS has been available for many years (today also the russian GLONASS) and often we have heard 'Why do not incorporate GPS at each base station?' unfortunately it is vulnerable solution to jamming and interferences. Moreover, GPS cells are everyday smaller and access to aerials is not always possible because are deployed indoors, in stadiums or shopping centers where access to satellite signals could no be practical or it is very expensive. Even CDMA operators who traditionally have relied on GPS, do not it consider any more as an acceptable solution due to operational and political reasons.

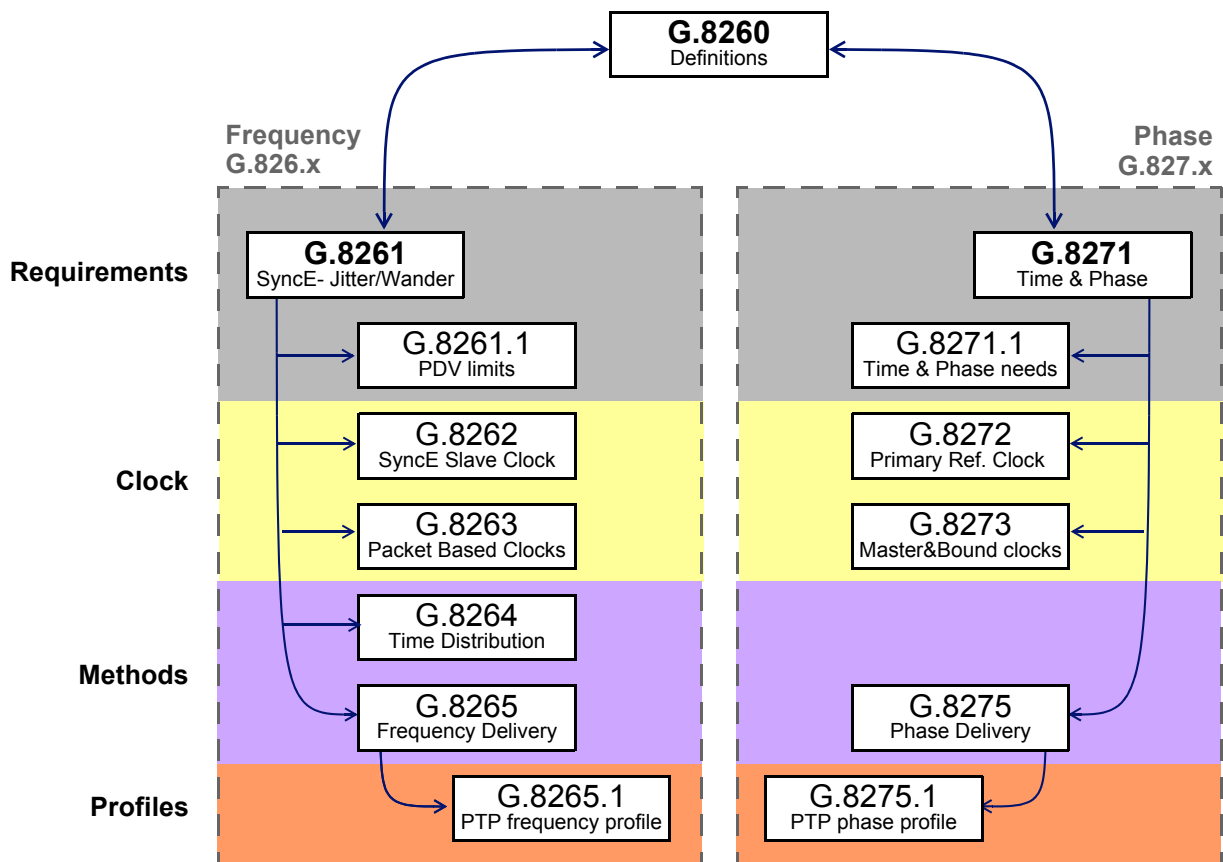


Figure 5 Timing distribution through packet based networks.

### Synchronous Ethernet

Synchronous Ethernet (SyncE) is an ITU-T standard that facilitates the transference of clock signals over the Ethernet physical layer. The signal should be traceable to a unique external clock for the whole network. There are a number of ITU-T recommendations about this standard (see Figure 5):

- G.8261 defines the Architecture and the wander limitations;
- G.8262 specifies Synchronous Ethernet clocks for SyncE;
- G.8264 describes the Ethernet Synch Messaging Channel (ESMC)

On many respects SyncE it is an evolution from SDH/SONET synchronization and this is the reason because it shares many concepts including the synchronization architectures and topologies (see Figure 6).

### Precision Time Protocol (PTP)

While Sync-E can provide the syntonization required by 2G and 3G networks; PTP is indicated for those networks that also require the phase, freq. and time synchronization.

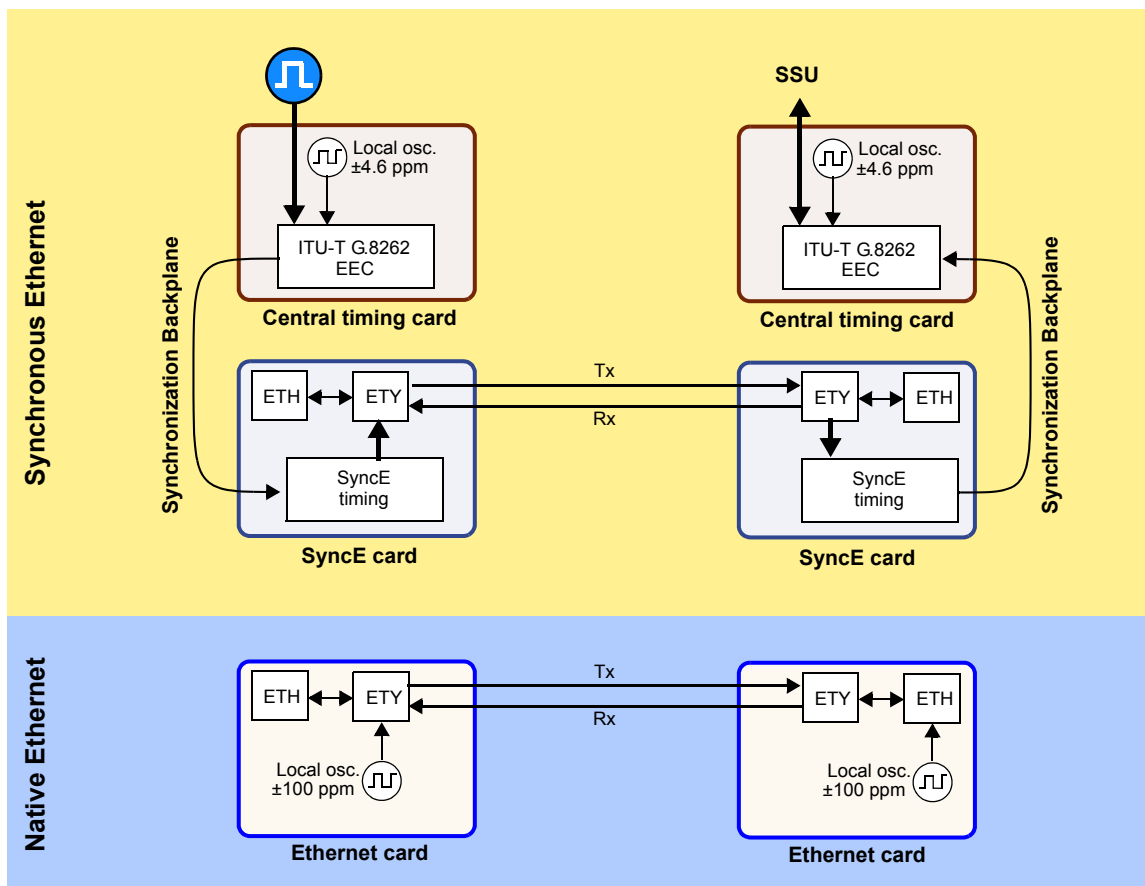
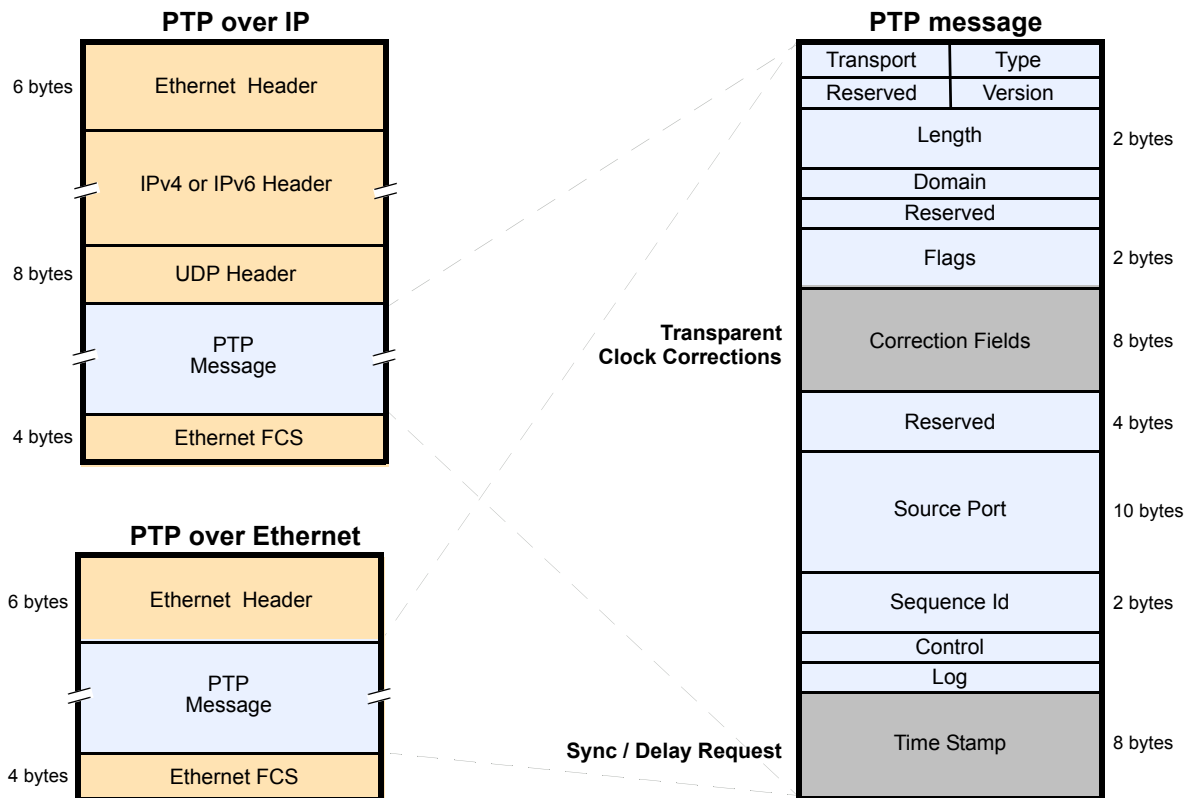


Figure 6 Synchronous Ethernet Architecture and comparison with conventional Ethernet.



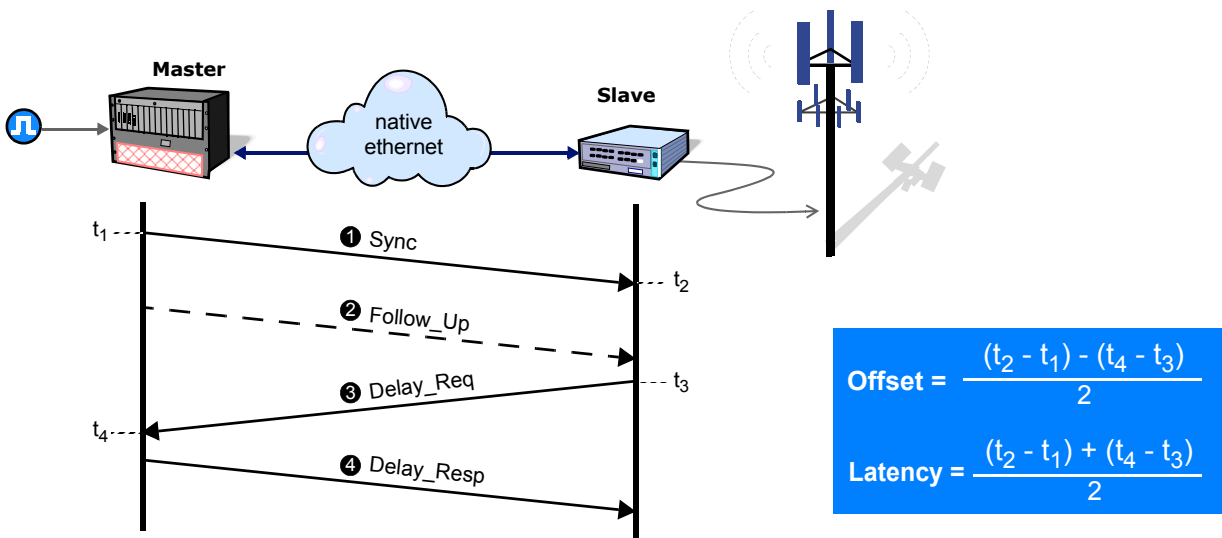
**Figure 7** IP and Ethernet encapsulations for PTP messages.

PTP is a 2-way time transfer protocol with hardware time stamping to transport the timing within Ethernet frames or IP packets. In comparison with SyncE intermediate nodes do not need to be upgraded and PTP can deliver not only frequency but also time and day synchronization that is required for TDD mobile networks (see Figure 1).

Interestingly PTP slaves communicate with short messages to the centralized Grand Master Clock via native Ethernet networks. This is a very good news indeed -the use of native networks- the unique requirement is to transmit PTP in high priority to avoid congestion, and try to control the QoS particularly packet delay variation (see Figure 8).

### 3. TIMING REQUIREMENTS OF MOBILE NETWORKS

Mobile operators are moving to a more efficient and higher capacity networks as there is more demand in terms of users and data but the available radio frequencies already are largely allocated, then operators increasingly use new techniques to squeeze more bandwidth from their existing spectrum allocations (see Table 1).



**Figure 8** Delay Request-Response mechanism used by the PTP. The basic parameters of Latency and Offset are computed from the t1, t2, t3 and t4 timestamps.

Depending on the technology Telecom Operators have different timing requirements. Some of them running GSM and 3G may still maintain legacy TDM links solely for syntonization and may want to eliminate that costly equipment. Others are focus on LTE see the impending need for distributing phase-synchronization and also want to avoid having to install GPS technology at every cell site.

**GSM, 3G**

GSM, 3G only require a frequency reference, it means that will be enough a TDM or SyncE based syntonization (see Table 1).

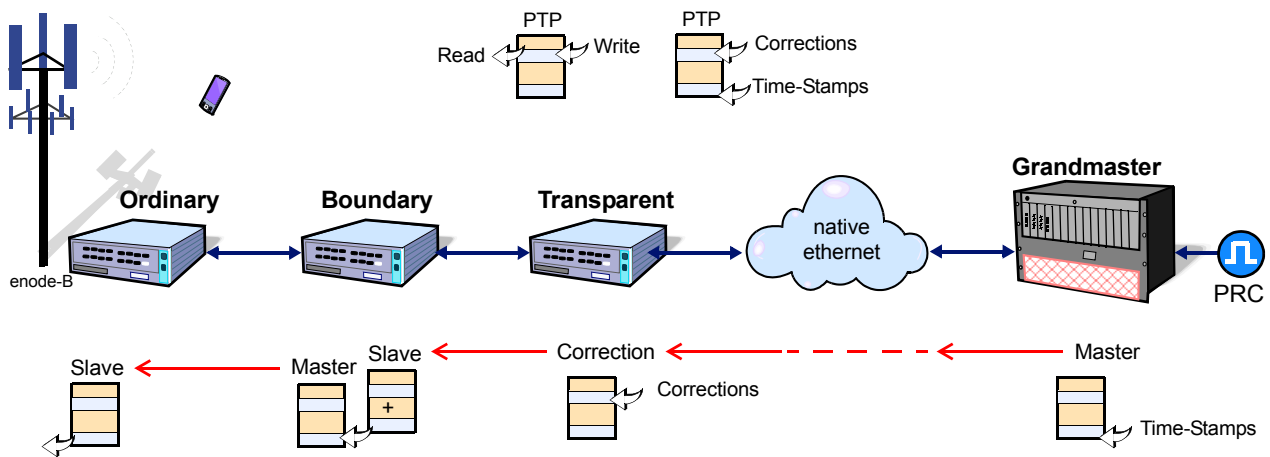
**Long Term Evolution (LTE)**

LTE-FDD (Frequency Division Duplex) timing requirements are similar to GSM and 3G. Only require a frequency reference. New LTE networks are very demanding on frequency and phase requirement, particularly those architectures that consider small cells, where the frequency reutilization is a key factor of performance..

**Table 1**  
Frequency & Phase requirements of wireless networks.

Wireless Architecture	Frequency Base / Air	Phase	Timing Alternatives
GSM, 3G, LTE-FDD	16 ppb 50 ppb	Not required	TDM, SyncE, PTP
CDMA-TDD	16 ppb 50 ppb	±3 µs to ±10 µs	PTP, GPS
LTE-TDD	16 ppb 50 ppb	±1.5 µs to ±5 µs (large cells)	PTP, GPS
LTE-TDD	16 ppb 50 ppb	±1 µs to ±1.5 µs (small cells)	PTP, GPS
Wimax-TDD	16 ppb 50 ppb	±0.5 µs to ±5 µs	PTP, GPS





**Figure 9** IEEE1588 Precision Time Protocol can be transported across legacy packet switched networks and is able to provide phase synchronization.

LTE is moving forward new timing requirements for not only frequency but phase synchronization as well. This is the case of LTE-TDD (Time Division Duplex) that uplink and downlink share the frequency to make the system more efficient. This scheme probes to be very flexible but it is necessary to provide an absolute time reference to use in a flexible way the available time slots.

## 4. PTP PROTOCOL DETAILS

PTP was defined in the IEEE 1588 standard that describes a **master-slave** architecture for timing distribution across Ethernet / IP packet network. The standard offers some key advantages to manufacturers and operators that can deploy PTP compliant equipment and avoid the cost of TDM and potential jamming, operational and political issues that come with deploying GPS receivers at every base station (see Figure 9).

In IEEE 1588 system can be found several types of clocks (see Table 2):

- A **ordinary clock** is a device with a single port connection that can play the role of master or slave depending on its position in the network.
- A **master** clock provides accurate time stamping to slaves clocks collocated at the downstream side.
- A **grandmaster** is the master clock situated at root timing, therefore is the clock reference, transmitting time information to the clocks of its segment.
- A **boundary clock** has multiple network connections, works as slave upstream and as master downstream. Then it bridges synchronization from one segment to another.
- A **transparent clock** pass through PTP messages adding in the correction field the time spent packets when traversing the device (see Figure 7).

**Table 2**  
IEEE 1588v2 Device Description

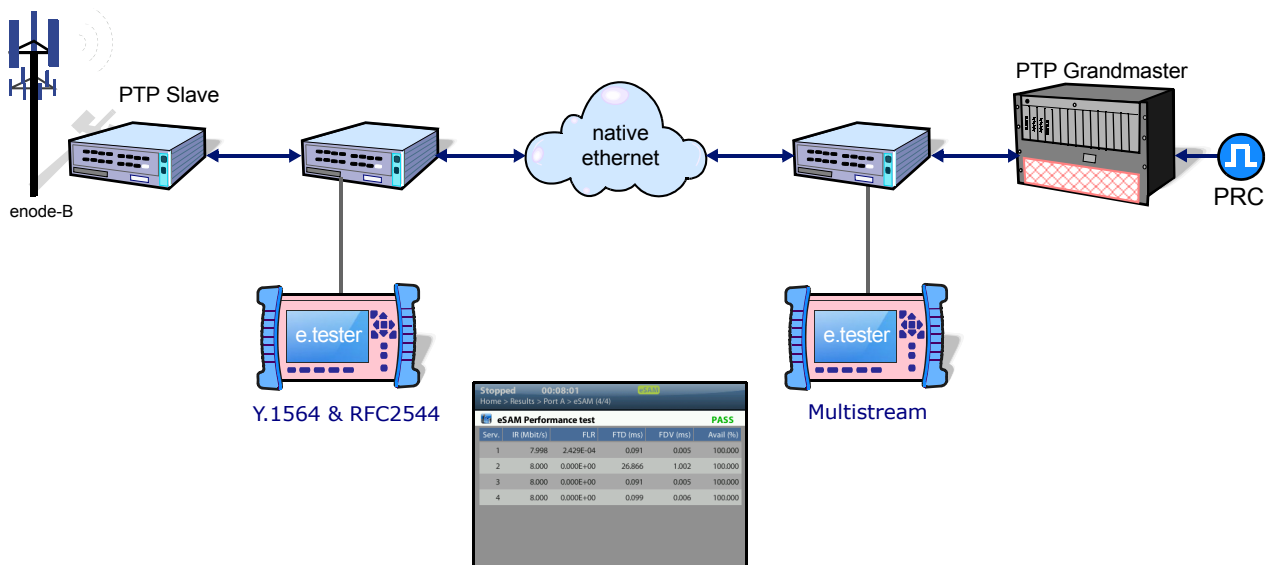
Clock	Description	Operation
Ordinary	Single-port device that can be a master or slave clock	Read/Write time stamps
Grandmaster	Ordinary clock that manages the reference time	Write time stamps and responds time request from other clocks
Slave	Ordinary clock that keeps synchronized to the masters and provides synchronization to its clients	Write time stamps and responds time request from other clocks
Boundary	Multi-port device that can be a master or slave clock	Read/Write time stamps
Transparent (end-to-end)	Multi-port device that is not a master or slave clock but a bridge between both forwarding / correcting PTP messages	Write corrections
Transparent (peer-to-peer)	Multi-port device that is not a master or slave clock but a bridge between both forwarding / correcting Sync and Follow-up messages	Write corrections

By using boundary and transparent clock functions in the synchronization chain, the effects of latency and packet delay variation are minimized. Master and slaves do exchange packets containing short messages to measure and eliminate phase errors.

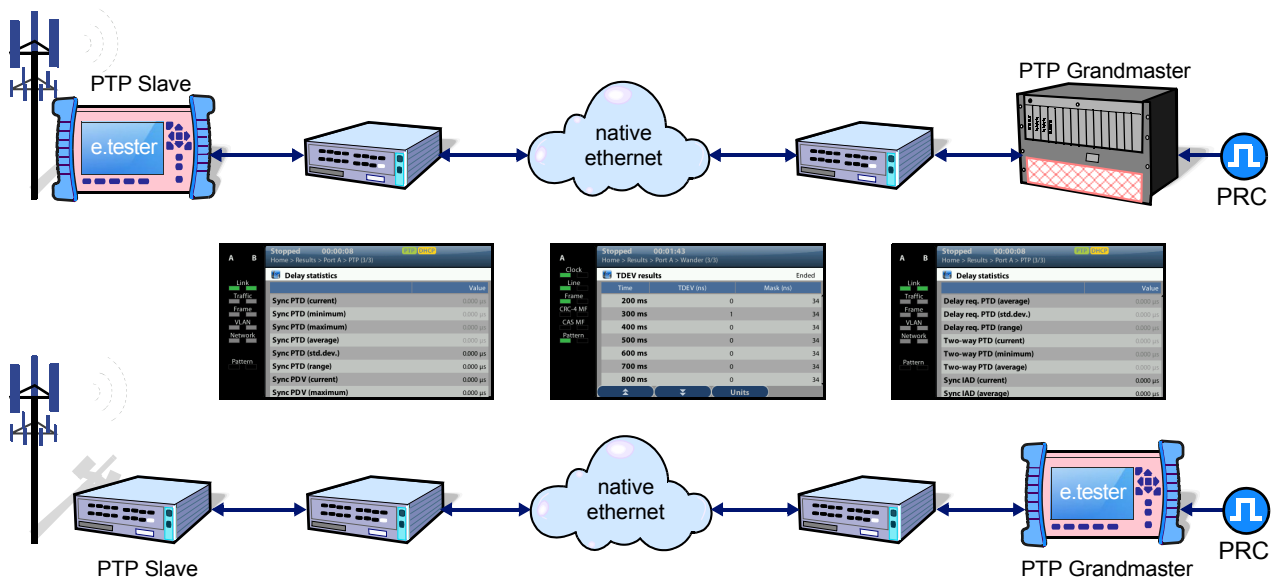
Using IEEE 1588v2 reduces the number of required GPS antennas and the associated cost, and it enables operators to distribute phase synchronization to sites where GPS is difficult to deploy.

### PTP Profiles

IEEE-1588 2008 introduced the Profile concept as a set of PTP optional features to support different types of applications. For instance a PTP profile may define Path Delay Control, the transport mechanisms required, node types, message exchange rate, unicast or multicast protocol. Profiles facilitate the interoperability between nodes and the deployment of PTP across telecoms networks.



**Figure 10** Ether.Sync or Ether.Genius executing the ITU-T Y.1564 (eSAM) to verify the KPI that affect PTP flows.



**Figure 11** ALBEDO Ether.Sync and ALBEDO Ether.Genius are testers that can emulate Master and Slaves nodes while measuring key parameters such as time offset, phase deviation etc.

## 5. INSTALLATION, TURN-UP & MAINTENANCE OF PTP

### Service Activation

The first step is the analysis of KPI of the network that has to transport PTP streams in terms of capacity and quality. They may determine the success -or failure- of the implementation. With Ether.Genius executing eSAM can be simulated a PTP service including the generation of background traffic with different traffic profiles.

The basic purpose of eSAM is to check that PTP frames are transported with the required performance in terms of Frame Total Delay (FTD), Frame Delay Variation (FDV), Frame Loss Ratio (FLR) and Availability to make sure that the SLA reserved for PTP messages is preserved by the network when required to do so (see Figure 10).

### PTP test and Measurements

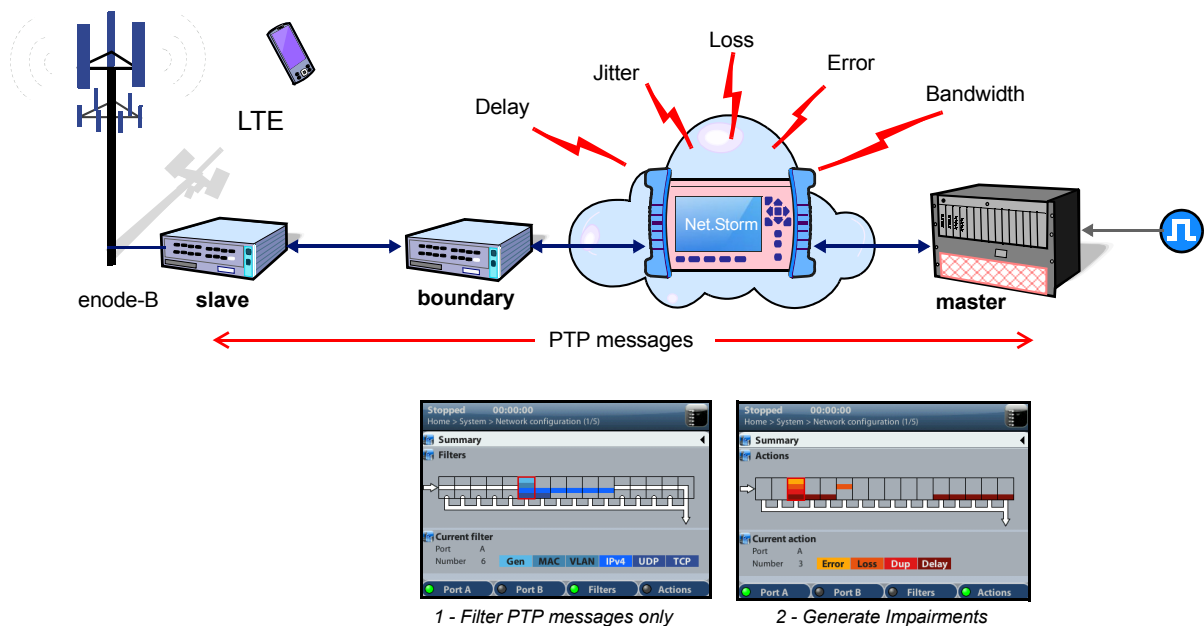
During the installation of a IEEE 1588v2 network, PTP message connectivity problems may occur between the master and slave units. For instance failure to establish PTP message connectivity makes achieving synchronization impossible and disables support for services. When troubleshooting these links, the ALBEDO Ether.Sync can be used in Terminate mode to capture PTP messaging on both the transmit and receive test ports up to 1 Gbit/s. In this mode, the ALBEDO Ether.Sync simultaneously generates, receives, and cap-

tures PTP messages on the circuit under test. Users can quickly identify higher layer protocol issues that may be associated with PTP messages and/or provisioning (see Figure 11).

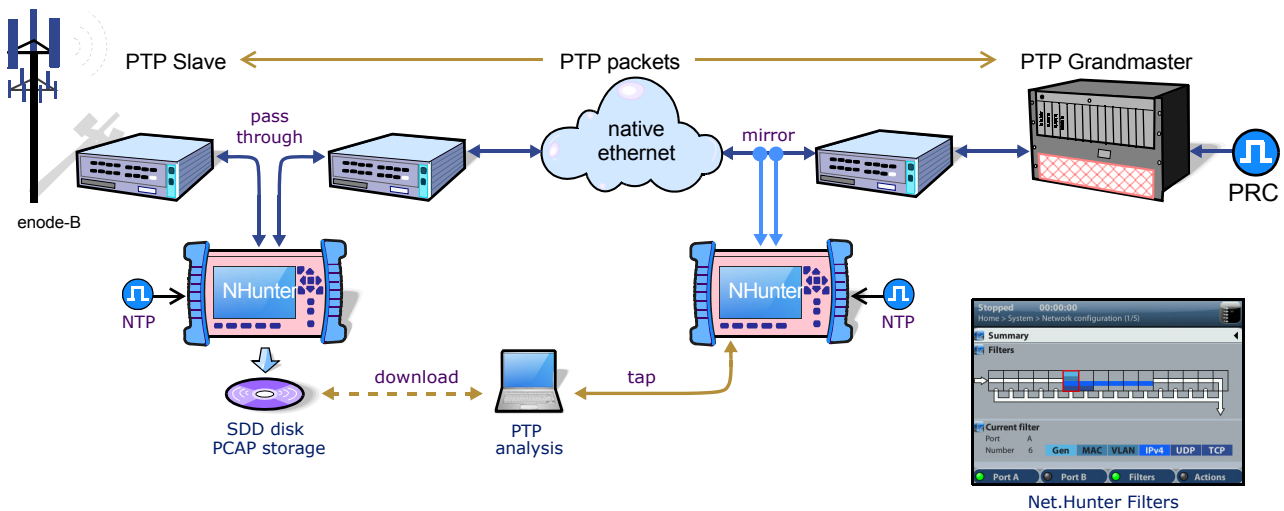
The protocol PTP is designed to work under network conditions including highly occupied networks. When there is a lot of contention the routing and switching of PTP messages could therefore be affected causing potential bad effects like packet delay variation in PTP messages will ultimately affect synchronization because it depends upon consistently timed message reception. Both ALBEDO Ether.Sync and ALBEDO Ether.Genius can emulate data plane traffic (up to eight streams) while PTP messages are transmitted simultaneously. Under these conditions, field engineers can verify if the new or the existing PTP network are capable to operate properly under many different load scenarios.

### Network Impairments

PTP protocol is supported by packet networks and therefore PTP packets may suffer the typical impairments including packet loss, packet delay, packet jitter, delay asymmetries in the paths, even out of sequence messages. These are major inconveniences that degrade the quality of the synchronization. Fortunately Packet jitter can be compensated by boundary clocks. However path asymmetry produce different delays between upstream and downstream, it is more difficult to filter and requires manually adjust it is. Despite the above mentioned difficulties clocks must remain stable minimizing these impairments and using the holdover function to keep synchronization in good shape an inside the tolerance masks (see Figure 12).



**Figure 12** Net.Storm can generate -in a 100% controlled way- packets impairments to verify how boundary clock manage against packet lost and packet delay variation (PDV or Jitter). Net storm can also be used to compensate delay asymmetries that cannot be filtered by boundary or slave clocks.



**Figure 13** *Net.Hunter is a compact solution to manage quality, troubleshooting threats, incidents and malware.*

ALBEDO Net.Storm is WAN emulator instrument that can generate network impairments at FPGA performance (full wire-rate) over IP / TCP / UDP networks such as: latency, jitter, loss, error, duplication and modification of the packets (see Figure 12). This is the right to stress the PTP network to verify how tolerant synchronization is under actual network conditions. It is of key importance also the ability of slave clocks to work in holdover maintaining a good timing. With Net.Storm it is also possible to force asymmetries and compensate them with an accuracy of nanoseconds.

### PTP packet captures

Using ALBEDO Net.Hunter engineers have all the advantage of hardware tap and overcomes those issues caused by PC based cards. It is a field handheld tap that can filter at wirespeed PTP flows in both direction the rest of the flows (protocols, data, etc) to pass with zero delay and no lost at all. PTP packets that are compliant with any of the 30 programmable filters (based on MAC, IP, TCP, Port, etc.) are copied and saved in an internal SSD disk with in PCAP format and afterwards packets can be analyzed in the lab. Alternatively copied of PTP packet can be forwarded to a LAN in real time to be analyzed with an external device<sup>1</sup>.

An interesting feature is that Net.Hunter can be synchronized therefore the captures of PTP packets with time-stamps can be very useful to study transparent clock performance, compensation timing, timing accuracies, etc. during the operation of LTE networks in-service and live traffic. Net.Hunter will never drop packets, working at full wirespeed in full duplex and unlike other capture alternatives it may also capture physical layer errors, FCS errored frames, and non-standard frames as jabbers (see Figure 13).

1. For instance a workstation equipped with a protocol analyzer that could be proprietary or freeware like Wireshark.

## Selected Bibliography

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aims

- + LEARN from business models and case studies
- + UNDERSTAND the potential of interoperability with legacy services
- + EXPERIENCE specialised synchronization network solutions
- + ASSESS different solutions for installation and maintenance