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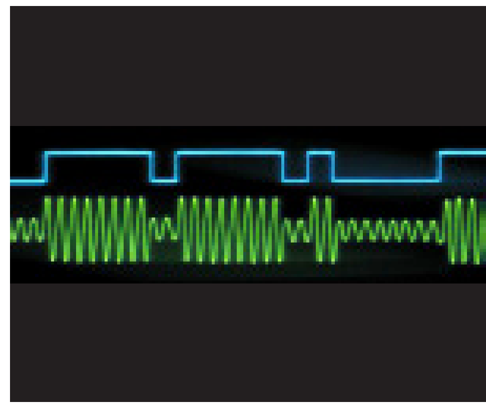
# Synchronizing IP Mobile Networks



WHITE PAPER

# Synchronizing IP Mobile Networks

## A Practical Guide to Synchronization For Long Term Evolution Wireless Systems

### THE BUSINESS CHALLENGE

As operators tested 3G killer applications a mobile internet generation emerged, taking for granted high-capacity access irrespective of time or location. Text messaging no longer satisfies the user needs, being replaced by bandwidth intensive social networking, picture messaging and streaming video applications. Unlike voice services, mobile broadband is "always-on", and must always be available.

An estimated 500 million subscribers will have access to mobile broadband by the end of 2011, exceeding the number of wireline subscribers[1]. Supported by generous data plans, smart handsets and wireless modems, the demand for mobile broadband continues to grow exponentially and is the new business opportunity for service providers.

**Mobile broadband has become reality. It has changed all our paradigms.**

But that opportunity is not without challenges.

Fiscally, data demand is growing exponentially, but the added revenue is incremental, placing pressure on capital and operating budgets. Since tariffs cannot be increased in proportion to demand, the cost per bit delivered must be reduced!

Technically, the data must be transported over the air, and then delivered via the backhaul (often referred to as the Radio Access Network) to the high capacity core network. Air interface protocols satisfy the current data demand, but the backhaul does not have the transport capacity needed for the data transfer.

**IP/Carrier Ethernet meets the mobile business needs ... increased bandwidth and for less money.**

With the largest part of the operating cost being attributed to the Radio Access Network, the linear relationship between bandwidth and cost for channelized E1/T1 circuits does not meet the financial goals. This is also true for leased circuits, despite falling prices. Ultimately, mobile operators need to transport more data for less money, and TDM backhaul is not a viable long term solution.

IP/Carrier Ethernet is a practical and therefore inevitable choice for the backhaul.

When looking at data forecasts, it was also evident that existing radio schemes won't meet future demands, and engineers were tasked with designing lower cost, flexible and more efficient wireless systems.

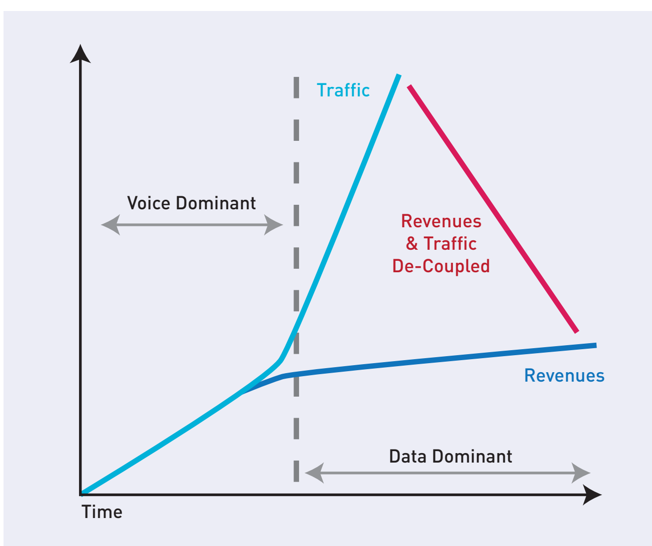



**FIG 1:** Revenue/Traffic Relationship

1 *Infonetics Research, Inc.*, Fixed and Mobile Subscribers *annual worldwide market forecasts October 2008*

The result... Long Term Evolution (LTE) and IEEE 802.16 WiMAX mobility. Many articles have been published on the relative benefits of LTE and WiMAX, but concisely stated, they offer important benefits for both consumers and operators:

- Radio transmission rate increases, with download links up to 200 Mbit/second (LTE).
- Low round trip latency (10 milliseconds).
- Gains in spectral efficiency, allowing more simultaneous users for a given bandwidth. This includes Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes.
- Underlying all IP transport networks.

**Data rate increases, latency reduction, spectral efficiency and backhaul bandwidth collectively drive the need for LTE.**

What is important to us is the IP transport network. IP meets the backhaul investment drivers... increased bandwidth and reduced cost. Combining the IP foundation with protocols that meet tomorrow's air interface demands makes LTE a compelling technology.

As we drive for "more performance and lower cost", our innovation sometimes depends on secondary, enabling technologies. This is especially true for IP transport platforms in the mobile architecture. Data can be transported through an IP network without synchronization, but by the same token, IP networks cannot transport synchronization naturally (as was the case for SONET and SDH).

What does this have to do with the IP backhaul? The answer lies in the origin of the base station's frequency reference. The handset (or UE) derives its frequency reference from the base station's air interface and operates at that recovered frequency. If the frequency difference between adjacent base stations is too big, the handset will not lock to the new BTS as the user moves into the adjacent cell, and the call will be dropped.

The air interface stability allows the user equipment to hand off calls between cell towers without interruption, and is central to the Quality of Service (QoS).

**Without a stable air-interface frequency reference, wireless mobility cannot be supported.**

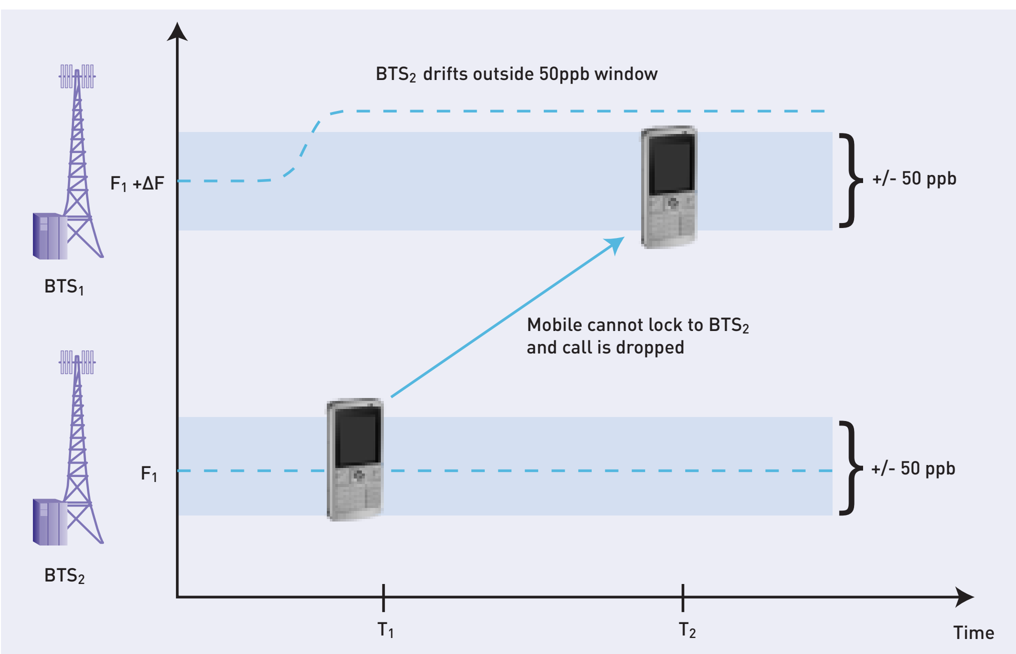



**FIG 2:** Mobility Requirements

From the table below, it is apparent that all base stations must support an air interface stability of 50ppb[2] or better, irrespective of the mobile protocols or technology generation. At first glance, this may seem a daunting task, but base stations traditionally sourced their frequency from the E1/T1 backhaul (assuming they meet the synchronization masks defined by the ITU-T G.823 or Telcordia GR.253). To meet the 50ppb air interface requirement, the span line stability must be approximately 15ppb.

| Mobility Standard | Frequency | Time/Phase |
|---|---|---|
| CDMA2000 | 50 ppb | Range: <3μs to <10μs |
| GSM | 50 ppb | |
| WCDMA | 50 ppb | |
| TD-SCDMA | 50 ppb | ±3μs inter-cell phase Δ |
| LTE (FDD) | 50 ppb | |
| LTE (TDD) | 50 ppb | +±3μs inter-cell phase Δ |
| LTE SFN-MBMS | 50 ppb | +±6.4μs inter-cell phase Δ |
| WiMAX (TDD) | 50 ppb inter BTS | Typically 1-1.5μs |
| Femtocell (FDD) | ~250 ppb | |

+ Standards being consolidated

**TABLE 1:** Mobility Air Interface Stability Needs

To get to the heart of the matter, the E1/T1 links traditionally provided the frequency reference to base stations. When replaced with Ethernet/IP, the link to the frequency source is lost, and the timing chain is broken. This is the design challenge for mobile backhaul planners.

**IP interrupts the frequency distribution needed by base stations. Synchronization must now be engineered into the network.**

The air interface frequency requirement is ever-present, but there are cases where precise Time of Day is also required at every base station.

- *The first is driven by technology.* Time Division Duplex (TDD) mode improves the spectral efficiency of the allocated bandwidth. Phase synchronizing base stations eliminate inter-cell interference by ensuring that adjacent uplink and downlink transmissions are coordinated. This can only be achieved by synchronizing all the base stations to the same Time of Day reference.
- *The second is driven by application.* Applications such as SFN-MBMS transmit video frames from multiple base stations, and accurately timing them allows the handset to rebuild the video stream coherently. In addition, Location Based Services that use Time of Arrival (TOA) to triangulate position also need precise time synchronization.

The means to deliver the required time accuracy has traditionally been to install GPS receivers at every BTS, and this will be discussed further as we explore next generation synchronization distribution.

**IEEE 1588 and SyncE are the two standards based methods for distributing frequency through packet networks.**

## REBUILDING THE SYNCHRONIZATION CHAINS

While the transport vendors built packet network elements, the timing community worked on methods to deliver Timing over Packet cost-effectively. The obvious goals were to keep it simple, cost-effective and predictable. Simple suggests using the network to deliver time and frequency (at the physical layer or in-band). There were many resultant methods to distribute precise time and frequency through the network, but those selected by standards organizations were Synchronous Ethernet (SyncE) and IEEE 1588-2008 (also referred to as PTP v2). Although not a packet technology, the use of GPS is also considered.

### Global Positioning System (GPS)

Technology advances and the widespread adoption of GPS have resulted in cost reductions, allowing GPS timing receivers to be deployed without the cost penalties of former versions. GPS is a high-performance solution, providing time, frequency and location information independently of the network, and has traditionally been used to deliver microsecond requirements at base stations.

One obstacle to GPS is service availability in metropolitan and indoor installations resulting from weak and reflected signals. The second concern is that GPS is not autonomous, and many wireless operators prefer not to be dependent on widespread GPS. Finally, the deployment and maintenance costs of GPS are not trivial, particularly in urban applications.

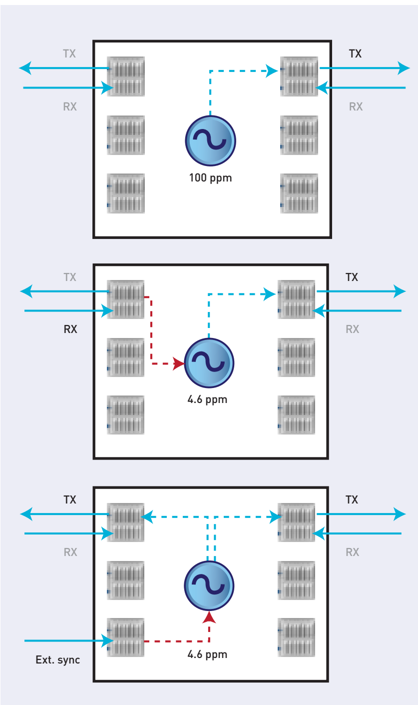
**Political barriers to GPS are declining, but widespread deployment demands a recovery contingency for GPS outages.**

New Global Navigation Satellite Systems (GNSS), such as Galileo, are being deployed and will satisfy the same application objectives as GPS. The political barriers to these systems may be lower in different geographies, but the urban canyon, autonomy and cost challenges are the same.

2 Fractional frequency offset (Δf/f) of 5 x $10^{-8}$

## Synchronous Ethernet (SyncE)

Synchronous Ethernet is a scheme that distributes synchronization over the Ethernet physical layer without compromising the asynchronous data switching functions. Based on the IEEE 802.3 standard for Ethernet, it is synchronous at layer one with the higher layers being asynchronous. There is no difference between a Synchronous and Asynchronous switch in the way the data is handled. The only difference is at the clock distribution and recovery layer.




Asynchronous switches receive data at the incoming line rate, and in adherence to IEEE 802.3, transmit data using a free-running clock of 100ppm (poor stability in synchronization terms, but suitable for the switching function).

SyncE switches, by contrast, use a more accurate 4.6ppm oscillator disciplined to the RX (incoming) line rate. There is a Sync relationship between the RX and TX, allowing the incoming clock to be propagated.

By adding an external sync port to the SyncE switch, a Stratum 1 reference can be introduced to, and distributed through, a packet network independently of the traffic.

Unfortunately cascading synchronous and asynchronous (traditional) switches will interrupt the originating (and accurate) sync flow, making SyncE a point-to-point frequency delivery method. This means that cascaded synchronous and asynchronous switches will not deliver the source frequency through the network. The 100ppm reference will be substituted in the asynchronous switch, breaking the timing chain.

**Cascaded SyncE and asynchronous switches will transport data, but cannot not distribute the source frequency.**

There are many similarities to SDH/SONET distribution, and this was by design. SyncE distributes frequency from a source to a destination, and Primary Reference Clocks are needed at the source. SyncE accumulates jitter and wander over the path just like SDH/SONET, and SSUs must be used to filter the jitter and wander per the ITU-T G.823 and Telcordia GR.253 guidelines.

**Planning for SyncE Jitter and Wander filtering follows the ITU-T G.823 guidelines.**

The 4.6ppm SyncE Equipment Clock (EEC) is the same one defined for SDH/SONET Equipment Clocks (SEC/SMC).

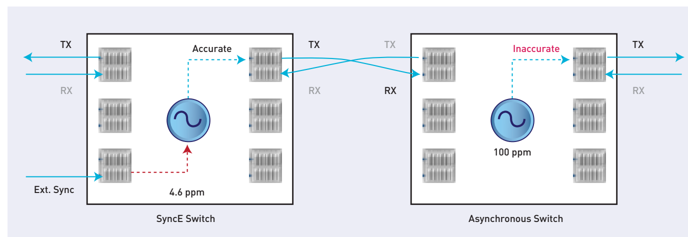



**FIG 4:** Broken Synchronization Chain

And just like SDH/SONET, SyncE only distributes frequency. SyncE does not distribute a Time of Day or phase reference.

In summary, SyncE has the advantage of being a deterministic *frequency distribution* method that is independent of the data flow. However, all the switches in a path must support SyncE, and widespread adoption will be governed by the cost and ease with which installed asynchronous switches can be upgraded.

### IEEE 1588-2008 (PTP v2)

The IEEE 1588-2008 protocol (also called Precision Time Protocol or PTP) is a standardized method to distribute accurate time and frequency over IP networks. The basis of operation is that packets carry timestamp information between a master (sometime called a server) and slave (sometimes called a client), and the slaves use the timestamps to synchronize to the master. Bidirectional flows eliminate the round trip delay to enhance the accuracy. Frequency can, in turn, be recovered from the disciplined Time of Day clock.

**IEEE 1588 is an in-band distribution system, eliminating the need for a dedicated timing plane.**

The 1588 timing and management messages are transported in-band with the mainstream traffic, eliminating the need for a dedicated timing plane.

IEEE 1588 was initially developed for industrial automation over Local Area Networks, but a second version, tailored for constrained telecommunication environments, was published in 2008. The pending ITU-T G.8265 Telecom Profile simplifies the diversity of configurable parameters needed to support WAN's, improving the protocol's interoperability.

What makes IEEE 1588 very attractive is the microsecond accuracy (and associated 1ppb frequency stability) that can be realized over managed Ethernet. This allows PTP platforms to support a wider range of applications than any other solution, addressing both the FDD and TDD modes of LTE.

**IEEE 1588 over Ethernet designed for QoS can deliver microsecond accuracy.**

Being packet based, IEEE 1588 is sensitive to the network behavior and the accuracy depends on the clock recovery algorithm and the packet jitter (also called Packet Delay Variation or PDV). In general, meeting the frequency requirement is moderately easy, but phase synchronization is more sensitive to PDV and requires added planning.

Fortunately the protocol designers foresaw this, and included on-path support in the specification. On-path support consists of Transparent and Boundary clocks that reduce the packet jitter, improving performance over long hop counts. On-path support will be discussed in more detail later.

## Network Time Protocol (NTP)

NTP is the most popular protocol for distributing time over LANs and WANs, and when looking at IEEE 1588, the similarities cannot be ignored. The reasons NTP is not used in high performance applications are the low transaction rate (1 per 64 seconds) and the software nature of the solution. NTP packets pass through the Ethernet PHY and Media Access Control (MAC) layers like any other packet. CPU processing for the timing requirements is not addressed until the software stack is fully processed. The NTP packets are therefore delayed by an indefinite time depending on the operating system latency, limiting the assured accuracy of the solution.

NTP will continue to be used in LTE for Call Detail Records and billing, just as it was in earlier mobile generations. NTP time synchronization is also used by switch and router elements in IP networks to monitor performance and optimize routing tables (with one way latency methods being notable). Carrier-class NTP servers distributed at mobile switching offices remains a fundamental component of any wireless system.

**Call Data Record management and routing tables are still dependent on NTP services.**

It is worth mentioning that a Femtocell assumes the user to be essentially stationery, and the 50ppb air interface for this technology was relaxed to ~250ppb. As a result, some Femtocell FDD solutions have embedded NTP clients that recover frequency from the Time of Day.

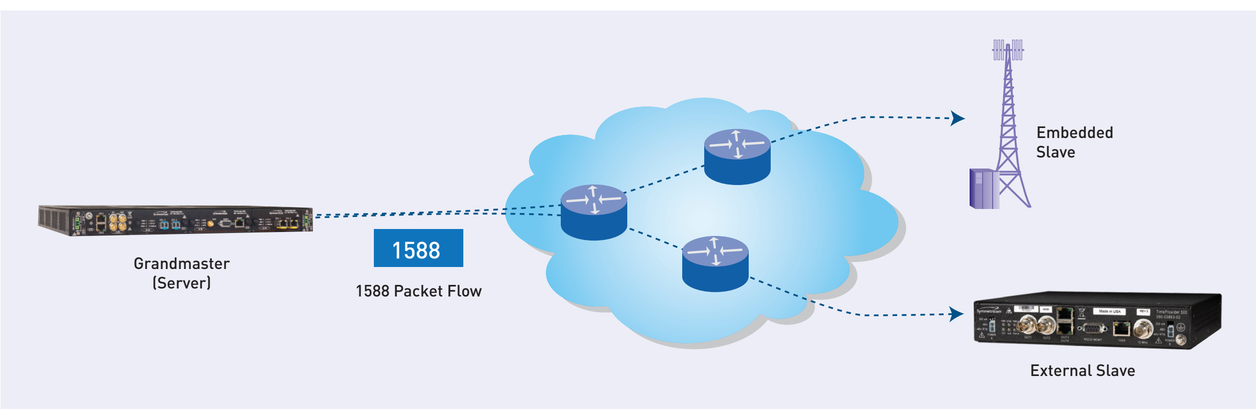



**FIG 5:** IEEE 1588 Architecture

### IEEE 1588-2008 (PTP) & SyncE In Perspective

How are IEEE 1588 (PTP) and SyncE similar? How are they different? And what does this mean to you?

Both SyncE and IEEE 1588 are standards-based methods to transport frequency (and time in the case of PTP) through the network to heal the broken synchronization chains. Where they differ is in implementation and function.

**SyncE and IEEE 1588 are complementary technologies and can co-exist in the network.**

The table below summarizes key differences between the two, but in essence SyncE is a conscious decision to add the feature to every switch between the source and the destination. To recap, cascaded synchronous and asynchronous switches will not transport synchronization (even though they can route data). IEEE 1588 is largely independent of the transport elements; largely because boundary and transparent clocks may be embedded in switching elements, but this is not a pre-requisite. This allows PTP networks to be built independently over diverse transport systems.

| Attribute | IEEE 1588 | SyncE |
|---|---|---|
| Capability | Frequency, Phase, Time | Frequency |
| Layer | Ethernet/UDP | Physical |
| Distribution | In-band 1588 Packets | Physical layer |
| Schema | Point to multi-point | Point to point |
| Transport Media | Ethernet, SHDSL, Microwave | Native Ethernet, Other in development |
| Interoperability | Standards-based Grandmaster & slave | Standards-based SyncE switches only |
| Sensitivity | Packet Jitter / Bandwidth utilization | Asynchronous switches |
| Standards | IEEE 1588, ITU G.8261/3/5 | G.8261/2/4 |

**TABLE 2:** IEEE 1588 / SyncE Comparison

It is important to note that SyncE and 1588 are not mutually exclusive. SyncE functions at layer one independently of the traffic. IEEE 1588 functions at higher layers (UDP/Ethernet) independently of the transmission rate. It is entirely possible that both technologies could be used on the same path - SyncE for frequency and PTP for time/phase. In reality, slaves that support both can converge on an accurate time very quickly by using the SyncE frequency to discipline the local oscillator.

**SyncE in it's current form cannot fulfill the phase requirements of LTE TDD or SFN-MBMS.**

## ENGINEERING FOR COST, PERFORMANCE & SIMPLICITY

### Selecting A Synchronization Strategy

Assuming a standards-based timing solution is chosen, synchronization will be based on either Synchronous Ethernet (SyncE) or IEEE 1588 (PTP), or the two together. Both these technologies have distinct advantages and disadvantages over each other. SyncE is deterministic and the performance is independent of the traffic. PTP can function over asynchronous switches, and distributes frequency and time with the data traffic.

Selecting one over the other is an economic reality as much as a technical reality, but setting aside the cost of upgrading the switches to SyncE, deployments with the following characteristics are likely to be based on IEEE 1588:

- Need time/phase such as LTE TDD and SFN-MBMS
- Do not have end-to-end SyncE switches (Ethernet)
- Function over diverse transports (microwave, Ethernet, SHDSL..)
- Share leased network sections, unless SyncE or a SDH/SyncE hybrid can be assured over the full path

**Selecting a Sync strategy is an economic and technical reality, determined in part by the mobility protocols.**

Keeping these limitations in mind, an operator planning to deploy LTE (TDD mode), or SFN-MBMS would typically select IEEE 1588 as the primary synchronization method. SyncE would only address frequency synchronization requirements. This does not preclude using a combination of SyncE or E1/T1 to synchronize legacy base stations.

For LTE specifically an IEEE 1588 strategy requires:

- Carrier-class Grandmaster clocks installed at strategic locations
- A managed Ethernet network designed for QoS
- Base stations with integrated 1588 slaves or with external sync ports, including 1PPS/ ToD for phase synchronization. By definition LTE base stations will not have external sync ports, but these may be available for early deployments.

## Defining the Sync Objectives

The air interface requirement defines the stability that must be maintained between the base station and the handset, typically over 1 time-slot. For LTE TDD, the frequency stability must be 50ppb, and the phase alignment ±3μS. The air interface needs must not be confused with the synchronization that needs to be delivered to the base station (on the backhaul interface).

**Sync Masks are used to define goals and determine whether those objectives are being met.**

We also know that when TDM network synchronization objectives are met, 50ppb or better can be maintained on the air interface. The TDM network performance objectives are defined in ITU-T G.823 and G.824 in the form of masks.

Masks define the MTIE limits (quality of synchronization) that a network should conform to over 100,000 seconds (~28 hours). Depending on where the clock signal is measured, there are two masks, the traffic and the synchronization mask. If the clock signal is being measured at an "end point", it must comply with the traffic mask.

If it is measured along the synchronization chain, it should comply with the more demanding synchronization mask.

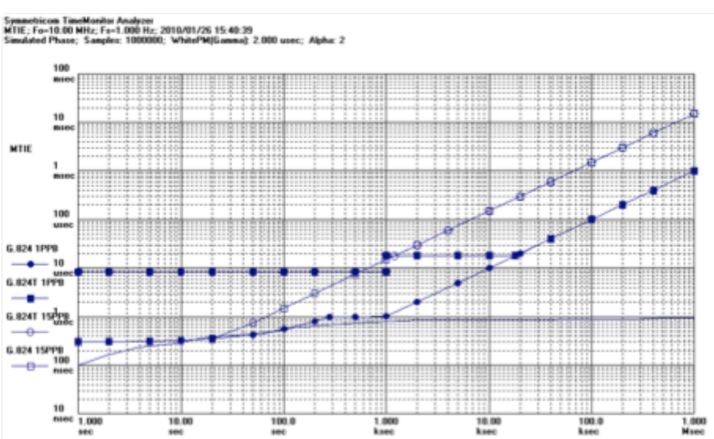
The BTS is an end point, and by definition, a carrier-grade service can be delivered if the network jitter is lower than (below) the traffic mask. This is also true in practice, but some operators are more cautious, and have selected the synchronization mask as the minimum performance to be met at their BTS interfaces.

How do we reconcile IEEE 1588 to the TDM mask? Packet networks don't transport synchronization, but the TDM interfaces are still synchronous. Ultimately, the 1588 packets must be converted to an analog source, and the quality of the recovered clock at the BTS must pass the MTIE test (as measured with a traditional SDH analyzer). If the measured result is under the mask, the 1588 system has worked. If not, it has failed and some level of re-engineering is required.

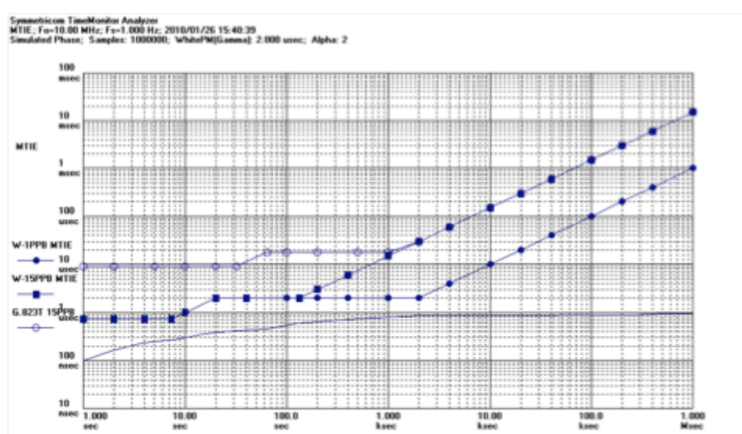
**Selecting the short and long Sync terms goals is the first step in engineering an all IP network solution.**

Because TDM masks only define the performance over ~28 hours, it is not uncommon for operators to define a long term stability requirement. A long term stability of 15ppb is typically specified and adequate for mobile base stations.

Finally, for TDD applications, the phase alignment (usually measured on a rising or falling edge) of the source (Grandmaster Clock) and slave must be less than the specified value, ±3μS for LTE with TDD support. This is also more accurate than the ±6.4μS for SFN-MBMS, addressing that application well.




1544 kbit/s hierarchy MTIE Masks (G.824)




2048 kbit/s hierarchy MTIE Masks (G.823)

**The 1588 slave's PDV rejection capability governs the quality of the recovered clock.**

The quality of the synchronization delivered to the BTS for an LTE TDD service would typically be defined as:

- Meet the Traffic mask as defined in ITU-T G.823 over the first 100,000 seconds
- Maintain a long term average frequency stability of 15ppb ($1.5x10^{-8}$) or better
- Maintain the phase difference between the source and the slave of less than/equal to ±3 microseconds.

### What Affects IEEE 1588 Accuracy?

What affects IEEE 1588 clock recovery, and how it is mitigated? First, let's set aside the attributes that don't affect 1588. Packet latency, packet loss and packet errors do not significantly impact the clock recovery protocols.

The quality of the recovered time and frequency does depend on:

1) The stability of the local (slave) oscillator

2) The Packet Delay Variation[3] (PDV) of the IEEE 1588 packets

3) The quality of the servo-loop algorithm in the slave.

It should be apparent that the Grandmaster has not been mentioned, and for good reason. The slave design determines the achievable performance. High-cost oscillators are not an option in base stations already under pricing pressure, so PDV (or the elimination of PDV) becomes the overwhelming consideration.

**Eliminating Packet Delay Variation (PDV) has the largest effect on 1588 clock recovery.**

PDV is governed by the bandwidth utilization, upstream/downstream path symmetry, and the number of hops (store and forward buffer devices) between the Grandmaster and the slave. There is not much that can be done about variations in bandwidth use, but the 1588 packet PDV can be reduced in two ways. First, by filtering PDV in the clock recovery algorithm and second, by reducing the number of switch and routing elements between the Grandmaster and the Slave during the network planning stage.

### On-Path Support: Pushing the Limits

As described earlier, one method used to reduce PDV is to limit the number of switching and routing elements between the Grandmaster and the slave. Where this is not possible or desirable, a second method is to minimize the effect of switch transit delays (the time that 1588 packets spend in the switch). To do that, the IEEE 1588 standard includes two new clock types, the Transparent Clock and the Boundary Clock.

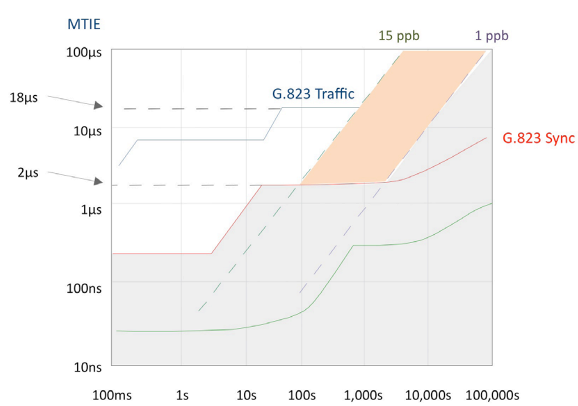



**FIG 6:** Performance Masks

3 Packet Delay Variation is similar to packet jitter, but includes the low frequency wander components.

*Boundary Clock (BC)*

The Boundary Clock was defined in both version 1 and 2 of the IEEE 1588 standards, and is a special form of network switch or router. From the network perspective, a boundary clock is a normal switch element, passing network traffic seamlessly.

**The burden of holdover and traceability belongs to the Boundary Clock when it is used.**

The clock plane is very different. The boundary clock has an embedded 1588 slave that synchronizes the internal clock from an upstream IEEE 1588 flow. It also has a Grandmaster function providing 1588 flows to downstream slaves within the network. One port of the BC is a designated 1588 slave port, and the remaining ports are 1588 master ports.

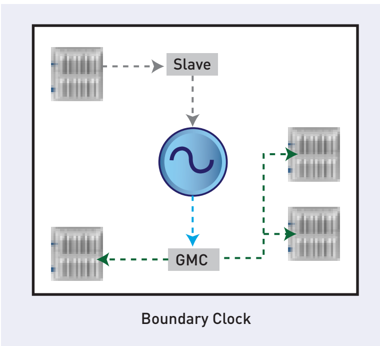



FIG 7: Boundary Clock

The master/slave functions in the boundary clock terminate a sync flow[4], and generate new flow(s), thus reducing the PDV that has been accumulated. Reducing the PDV is important, but in telecommunication applications, the Grandmaster is a carrier-class device with high stability holdover oscillators, management and resilience. The ability of the boundary clock to provide the same capability will depend on the 1588 implementation by switch vendors.

**Transparent clocks preserve the integrity of the sync flow, but are limited in encrypted networks.**

*Transparent Clocks (TC)*

Transparent Clocks were added to the second version of the 1588 standard to support cascaded topologies. Like boundary clocks, transparent clocks are a special form of network switch or router. Unlike boundary clocks, timing is not recreated, but the residence time (time that 1588 packets spend in a switch) is measured and reported to the slave. The transparent clock does this by inserting the residence time into the *correction* field in the *sync*, *delay-request* and *follow-up* messages.

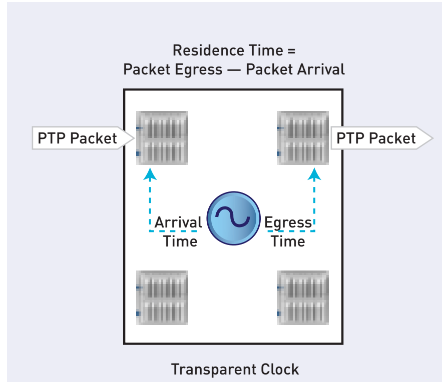



FIG 8: Transparent Clock

Two transparent clock modes are defined, peer-to-peer and the more widely advocated end-to-end version, accumulating the residence time of all the Transparent Clocks (switches) in the correction field. This allows the highly variable residence periods to be removed from the round trip delay calculation, reducing the PDV considerably.

We know that boundary and transparent clocks reduce the 1588 message PDV, and can increase the achievable performance for a fixed path length, or increase the path length for a fixed goal. But is it necessary?

As our frequency and phase results show, boundary and transparent clocks are not necessary for FDD mobile systems (assuming the number of links between the MME and eNodeB is typical). Depending on the slave clock performance, TDD applications with phase requirements can also be met without on-path support.

**On-path support is not always necessary for IEEE 1588 applications, particularly for frequency distribution.**

4 *Sync*, *Follow_Up*, *Delay_Req*, and *Delay_Resp* messages.

When functioning over a managed, symmetric metro Gigabit network, engineered for QoS, with 5 to 10 switching elements and controlled load, the Symmetricom slave can typically deliver 1ppb frequency stability and ±1 microsecond of phase accuracy[5]. These values will vary as a function of traffic load, switching jitter and path asymmetry. Having said that, a well-designed slave will benefit from boundary and transparent clocks.

**High quality clock recovery algorithms have demonstrated the extent to which PDV filtering is effective.**

In a world characterized by rapid change, the ITU-T working group's decision to exclude on-path support from the Telecom profile is a welcome step in reducing early deployment risk and complexity. But to ensure that your investment is protected, the slaves that you buy today must process the *correction* field in the PTP messages. This will ensure that the 1588 slaves can take advantage of on-path support elements if added in the future.

### Deployment Made Easy

Simple deployment guidelines ensure the best 1588 results:

- First select a high performance, high-reliability Grandmaster clock that has capacity for the number of slaves expected, now and in the future. A system that is scalable to 1,000 slaves, at a transaction rate of 64 per slave is typical.

**Validation of the slave's ability to use transparent switch delays is key to a future-proof solution.**

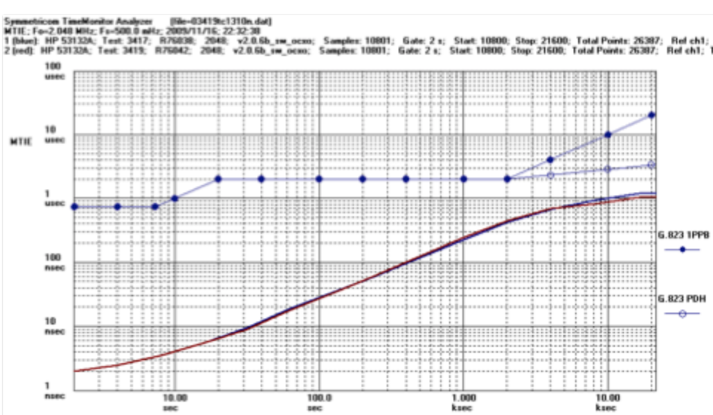
The Grandmaster capacity can be checked by dividing the maximum transaction rate by the number of served slaves and the number of transactions per second. If the demand exceeds the capacity, additional modules (or even Grandmasters) can be added to share the load. Served slaves is the sum of the slaves that are expected to obtain sync flows from a Grandmaster routinely, and those that could request the service if their designated GMC clock fails.

**Probing a representative sample of backhaul links provides insight into the PTP capability of path.**

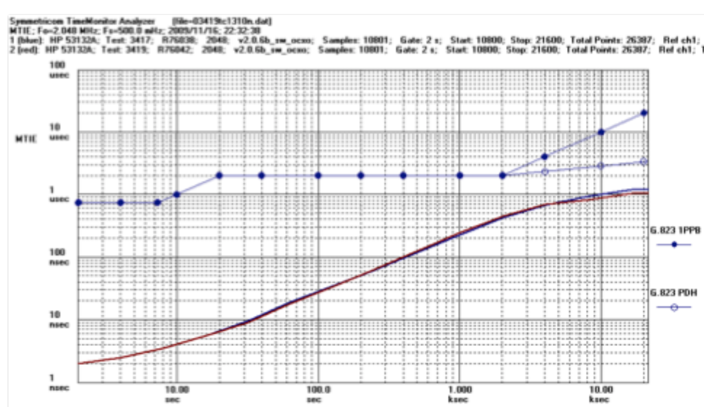
- Second, select a good quality 1588 slave that has been designed to work over the transport being used (e.g. Native Ethernet, Ethernet over SDH, Microwave and SHDSL). Embedded slaves will become commonplace, but stand-alone slaves allow early deployment risks to be reduced, as well as serving the large installed base of legacy devices that can only accept the DS1/E1 Sync references.

- The next step is locating the Grandmasters based on the message rate of the Grandmaster and the PDV that each slave will experience. Cost considerations encourage fewer Grandmasters functioning through more switches and routers. Robustness calls for more Grandmasters, with fewer links between the Grandmaster and slave. Telecommunication networks favor robustness for Quality of Service.

Experience has shown that the best place to locate the Grandmaster is at the RNC. LTE does not have a dedicated RNC, but it is reasonable to assume that the MME will be




MTIE (2048 Output, 10 Switches)




MTIE (1PPS Output, 10 Switches)

5 The solution referred to is the Symmetricom slave. Not all slaves have the same performance and results will vary.

located at the same locations as the RNC or aggregation nodes in the foreseeable future. The number of hops between the MME and eNodeB will typically be about five. In addition, the Ethernet path is likely to be managed, and a reasonably low PDV can therefore be expected.

- A representative sample of links should be probed to validate the Grandmaster location assumptions. Probing the network in this case refers to characterization of the PDV using a 1588 tool, and not the measurement of data packet latency or loss.
- And finally, the 1588 elements should be managed for faults, availability and synchronization performance. This is especially true for boundary and transparent clocks if they are used. If working correctly, on-path support can improve the result, but if it does not function correctly, the impact on clock recovery can be devastating.

Refer to the Symmetricom document "Deployment of Precision Time Protocol" for a more detailed IEEE 1588 planning guide.

## CONCLUSION

Although revenue is derived from voice services today, mobile broadband is the new business for service providers. To be viable, high bandwidth must be offered for less revenue, and be augmented with value added services. LTE and IP mobile backhaul are two significant steps in that direction.

The economics for IP backhaul is compelling, but IP creates synchronization discontinuities that must be consciously addressed in the network. The international community has accepted two new methods to distribute synchronization through packet switched networks. The first is Synchronous Ethernet, that transports frequency at Layer 1 for a deterministic result. The second is the IEEE 1588 precision time protocol that functions over higher layers. IEEE 1588 is more versatile, but is sensitive to network behavior. It is important to remember that SyncE and IEEE 1588 are not mutually exclusive and can be used together in some networks.

**Probing a representative sample of backhaul links provides insight into the PTP capability of the path.**

**Standards based solutions are interoperable and will grow with tomorrow's needs.**

Both methods are valuable to network planners for FDD mobility protocols, but IEEE 1588 is the preferred method for TDD and SFN-MBMS applications that require frequency and phase.

On-path support elements (boundary and transparent clocks) are not necessary in most FDD applications, and depending on the client performance and network design, on-path support may not be necessary for TDD applications. An improvement in the quality of the extracted clock can be expected if on-path elements are used and managed from a time perspective. Minimizing the use of on-path support in the short term helps reduce early deployment risks.

Ultimately, deploying a standards-based synchronization solution for next generation mobile networks is key to investment protection, as well as meeting long term requirements. A universal synchronization platform is most cost-effective, more robust and plays a large part in the optimization of the network.

To find out more about next generation synchronization, contact your local Symmetricom representative, or e-mail us at expertadvice@symmetricom.com

## ABBREVIATIONS USED

BC.......... Boundary Clock

BTS......... Base Station Transceiver

CES......... Circuit Emulation Service

DSL......... Digital Subscriber Line

EEC......... Ethernet Equipment Clock

ETSI........ European Telecommunications Standards Institute

FDD ........ Frequency Division Duplex

GigE........ Gigabit Ethernet

GMC........ Grandmaster Clock

GNSS...... Global Navigation Satellite System

GPS ........ Global Positioning System

IEEE........ Institute of Electrical and Electronic Engineers

IP ........... Internet Protocol

ITU-T ...... International Telecommunication Union

LBS......... Location Based Service

LTE ......... Long Term Evolution

MBMS..... Multimedia Broadcast Multicast Service

MTIE ....... Maximum Time Interval

NGN ....... Next Generation Network

NTP ........ Network Time Protocol

PDV......... Packet delay Variation (synonymous with Packet Jitter)

PTP......... Precision Time Protocol

PWE........ Pseudo-Wire Emulation

SEC......... SDH Equipment Clock

SDH ........ Synchronous Digital Hierarchy

SFN ........ Single Frequency Network

SONET.... Synchronous Optical Networking

SMC........ SONET Minimum Clock

SyncE ..... Synchronous Ethernet

TC .......... Transparent Clock

TDD ........ Time Division Duplex

TDM........ Time Division Multiplex

TOA......... Time Of Arrival

UDP........ User Datagram Protocol

UE.......... User Equipment

UTC......... Universal Coordinated Time

WAN ....... Wide Area Network