Traceable Frequency, Time, and Phase for LTE TDD and LTE Advanced

Overview and Objective

As wireless operators are rushing to build Long Term Evolution (LTE) networks based on time division duplex (TDD), frequency division duplex (FDD), and/or LTE Advanced (LTE-A) many are facing a familiar challenge - how to architect the network synchronization and timing requirements cost effectively for both the short and the long term. Figure 1 illustrates the rapid increase in global mobile data traffic that is driving the deployment of LTE, and therefore more packet based synchronization. To enhance spectrum efficiencies and pack in more subscribers, LTE, and LTE-A in particular, has introduced some innovative technologies such as carrier aggregation, multiple input multiple output (MIMO), coordinated multi-point (CoMP), and enhanced inter cell interference cancellation (eICIC). To fully take advantage of these features operators must first evaluate their end-to-end network timing and synchronization needs as some of these technologies require phase synchronization engineering rather than classical frequency pulse distribution. Such an evaluation can be a confusing and daunting task, and relying on poor or misguided information can lead to costly mistakes. This paper will define timing requirements, describe usage, and recommend some best practices designed to help operators correctly architect network timing the "first time".

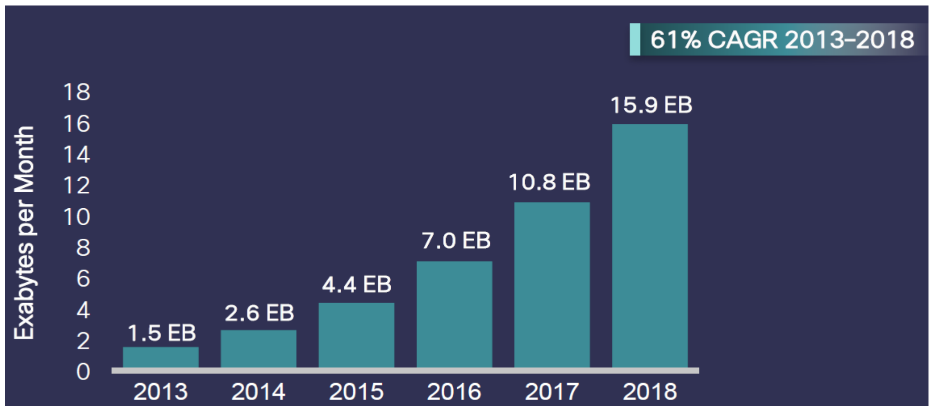

Figure 1. VNI Global Mobile Data Traffic Forecast, 2013-2018
(Source: Cisco VNI Global Mobile Data Traffic Forecast, 2013-2018)

LTE and LTE-A: Drivers and Network Requirements

Key advancements brought about in LTE and LTE-A and their impact on network timing and synchronization that directly influence the quality of services rendered to end customers are summarized below.

Coordinated Multi-Point (CoMP)

CoMP is a technique used to avoid interference and increase spectrum efficiency. This technique requires close coordination between the user equipment (UE) and the evolved Node B (eNodeB). The UE has connections with multiple eNodeBs at the same time. The uplink and downlink are coordinated and managed. For effective CoMP there should be an offset of +/- 0.5 µs between the eNodeBs in terms of time reference.

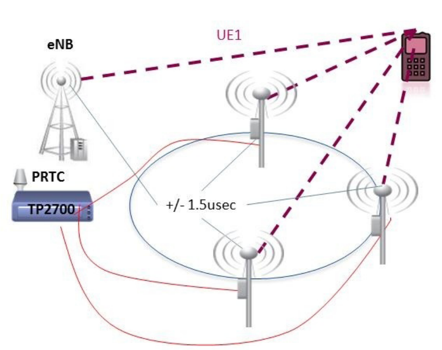

Figure 2. Example of CoMP or eMBMS Transmission and Reception

Evolved Multimedia Broadcast Multicast Service (eMBMS)

eMBMS is a point-to-multipoint interface that is designed to provide efficient delivery of broadcast and multicast services with a focus on video content.

The same signal is transmitted synchronously by multiple ENodeBs within a multicast broadcast single frequency network area.

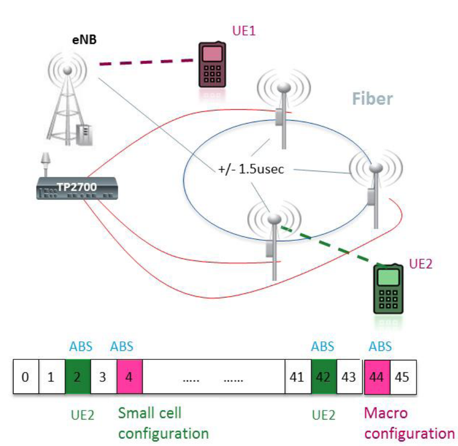

Figure 3. Enhanced Inter Cell Interference Cancellation (eICIC)

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The UE has connections to multiple eNodeBs at the same time to improve signal-to-noise ratio and seamless handoffs. Up to 60% of blank sub frames can be used to carry multicast video traffic.

Tight time and phase alignment of the eNodeBs, +/- 1.5 microseconds is required to control the timing of when the frames are transmitted. Figure 2 shows a typical configuration for CoMP or eMBMS deployments.

Enhanced Inter-Cell Interference Cancellation (eICIC)

eICIC (Figure 3) is currently used to mitigate the interference between eNodeBs. Almost blank sub frames (ABS) are utilized to reduce the interference. This technique needs phase/time to control the timing when the frame is issued and has to maintain a +/- 1.5 µs accuracy.

In addition to implementing CoMP and eICIC, next generation wireless networks need dense distribution and coverage capabilities to cater to a multitude of nodes to offer voice, data, and video services. They also need to evolve to Machine to Machine (M2M) communication technology.

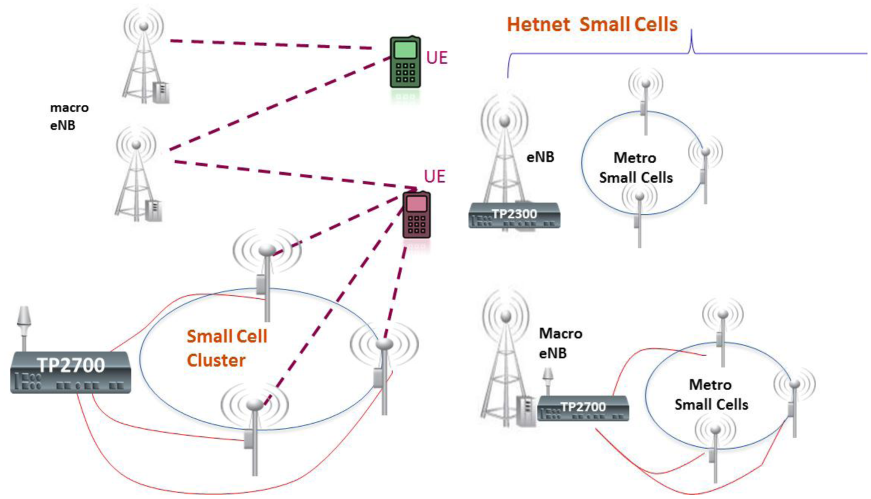

Figure 4. HetNet Small Cells Deployment

Heterogeneous Networks (HetNets)

As operators begin to utilize higher frequencies to deliver higher bandwidth, challenges such as coverage, and penetration into buildings occur. Deployment of small cells (indoor and outdoor) along with eNodeBs is becoming common practice. Operators deploying small cells also face many challenges such as providing synchronization and timing to nodes at the very edge of the network. HetNets are very effective in increasing network capacity. (Figure 4)

In many cases, the same content needs to be delivered at the same time by neighboring base stations. Downlink to UE is typically managed by the eNodeB. For a LTE-A deployment, if phase alignment is not good, the interference cannot be handled by cyclic prefix. It requires close synchronization between eNodeBs. There is a +/- 1.5 µs inter-cell alignment requirement that needs to be met.

Carrier Aggregation

LTE-A is increasingly using TDD to deliver the benefits of carrier aggregation and this causes stringent demands on the timing of frames utilized at the edge of the network to switch between various air frequencies in use.

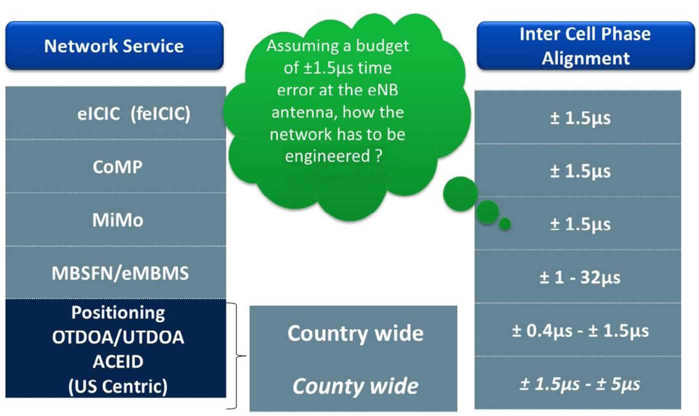

Figure 5. LTE TDD and LTE-A Require Time-Phase Alignments

Application	Frequency Network / Air	Phase	Note
LTE – FDD	16 ppb / 50 ppb	NA	Deploying eICIC, CoMP & MIMO adds LTE-A phase requirement
LTE – TDD	16 ppb / 50 ppb	± 1.5 µs	≤3 km cell radius
		± 5 µs	>3km cell radius
LTE MBMS (LTE-FDD & LTE-TDD)	16 ppb / 50 ppb	± 1.5 µs	Inter-cell time difference
LTE- Advanced (eICIC, CoMP & MIMO)	16 ppb / 50 ppb	± 1.5 µs (± 5 µs)	In discussion in 3GPP

Figure 6. Phase and Frequency Requirements for LTE and LTE-A

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Timing and Synchronization Requirements

It was referenced earlier that LTE TDD and LTE-A require time/phase alignment to coordinated universal time (UTC) or international atomic time (TAI) precision time protocol (PTP) time scale at the eNodeB to within +/- 1.5 µs. In addition to the phase requirement there is a voice hand-off requirement that drives a frequency accuracy requirement of 50 ppb at the air interface and 16 ppb at the network interface. Figure 5 summarizes the phase and frequency requirements for both LTE (FDD and TDD) and LTE-A per 3GPP (R10+) and ITU-T (G.8265.X for frequency and G.8275.X for phase).

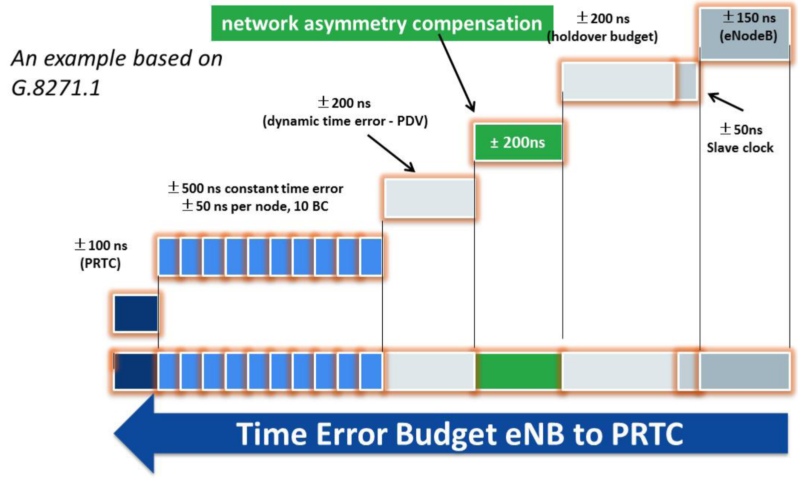

Figure 7. Levels of Asymmetry in Timing and Synchronization

The International Telecommunication Union (ITU) standards bodies have introduced two consented standards related to managing the delivery of UTC traceable time and phase, not arbitrary phase, using PTP for LTE TDD and LTE advanced applications—G.8275.1 (full on path support) and G.8272 (primary reference time clock). They are in the process of developing a third standard, G.8275.2 (partial on path support) that is applicable to networks with legacy infrastructure that does not support boundary clocks or synchronous Ethernet technologies.

It's an Asymmetric World

In addition to frequency and phase/time requirements to deliver LTE and LTE-A at the edge, there are varying levels of asymmetry in timing and synchronization depending on the type of backhaul and core network technology being used (Figure 7). Typically, for LTE and LTE-A, network operators and service providers work with a certain error budget across their network. This is measured from the end point to the closest primary reference time clock (PRTC). Per ITU-T G.8272 the PRTC must be traceable to +/- 100 ns accuracy to UTC. This important requirement is typically met by referencing the PRTC to a global navigation satellite system (GNSS) receiver engineered to assure 100 ns traceability to UTC under all operating conditions.

For a production network such as a 150 km transmission network that uses synchronous optical networking (SONET) OC192 or optical transport network (OTN) ODU0; for the same dense wavelength division multiplexing (DWDM) wavelength 40 µs of network asymmetry is observed. In addition, a 2 ms latency (in both OTN and SONET) is noted. For SONET a jitter of 200 ns and for OTN a jitter less than 4 ns is observed. SONET also had a wander of +/-300 ns.

Based on real network tests, a worst case time error of 24.646 µs and a best case of 225.92 ns were observed. In either case, 200 ns of budget used today for transmission asymmetry is not sufficient enough and requires compensation in the network.

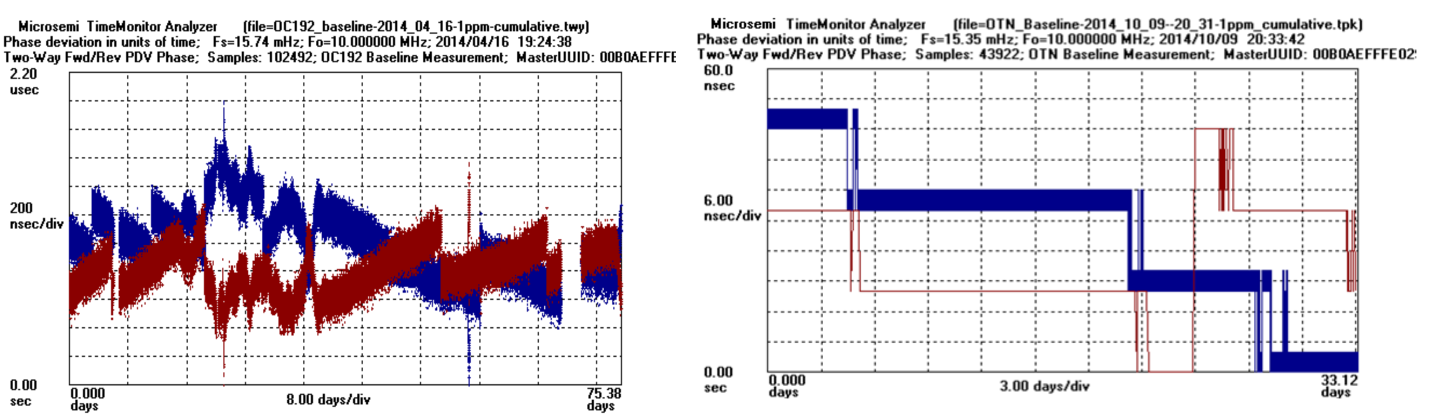

Figure 8. SONET and OTN TimeMonitor Analysis

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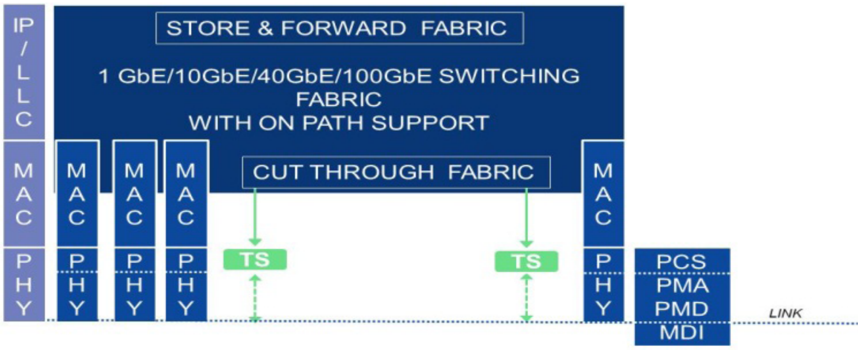

Figure 9. Fabric Asymmetries Originate from Queuing Mechanisms with or without Congestions

Boundary clocks (BC) and transparent clocks (TC) based on timestamps eliminate most asymmetries but there are other asymmetries that originate from the following:

- Load asymmetry (switches): Originates from switches when dealing with dynamic load conditions in reverse and forward path. Network engineers budget about +/- 50 ns of error for each hop. There is a measured typical delay dispersion range of 67 ns from transport stream (TS) to media dependent interface (MDI), which is above the budget by 17 ns.
- Physical network path asymmetry: This is related to the different physical fiber lengths in the uplink versus the down link. This error builds up hop to hop and route to route, and must be physically measured and manually compensated to assure 1.5 µs end-to-end timing accuracy.
- Fabric asymmetries: These typically originate from queuing mechanisms with or without congestions.

Other asymmetries originate from small form-factor pluggable (SFP), or C form-factor pluggable (CFP), or CFP2 from the PHY layer that is not MDI. There are also asymmetries from optical/physical link/path.

For many deployments, time transfer offsets with a grand master clock (GMC) in a central office (CO) and a BC at the edge due to asymmetry in the network were observed. This will cause interference issues with overlapping cells using GNSS or connected to a different BC.

Technologies and Solutions

Boundary clocks (BC) and transparent clocks (TC) based on timestamps eliminate most load and switching devices asymmetries but there are other asymmetries as described below and this calls for a better compensation and correction in the network.

Plan A: Design the DWDM to meet the time budget.

- Limit the distance. Eridium dopped fibre amplifier (EDFA) or Praseodymium dopped fibre amplifier (PDFA) optical amplifiers are not required. Not practical all the time.
- Limit the number of hops for each SFP and calibrate each fiber length to 0.01% or better. Not practical all the time.
- Use better fiber (single mode DSF/NZ-DSF; similar to G.655). G.652 is about 70% of the installed base and will be high CAPEX to redeploy.

Plan B: Fix the problem after by engineering a timing solution.
Do asymmetry compensation/hop.

Plan C: Do not utilize DWDM

Instead, use Gigabit-capable Passive Optical Networks (GPON) with automatic delay compensation (G.984.3).

Plan D: Work with whatever is currently deployed. Move PRTC closer to edge or review the budget allocation.

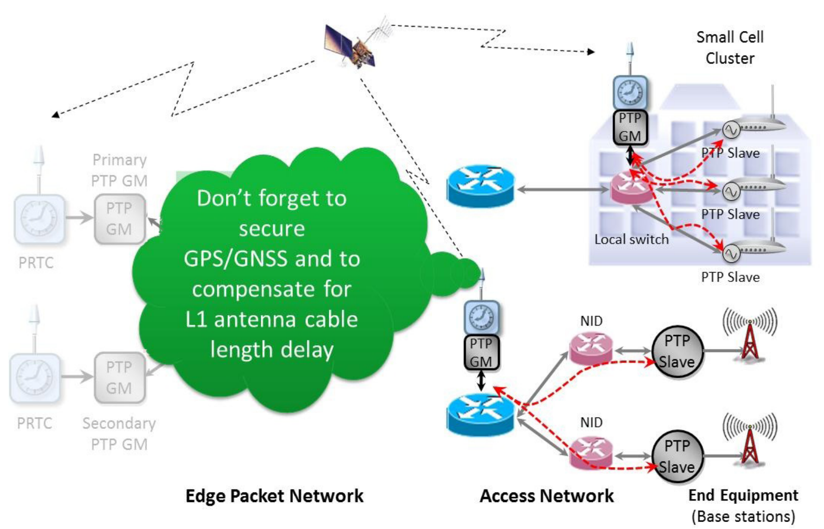

Figure 10. PRTC Closer to the Edge Ensures Network Redundancy and Prevents GPS Outages

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Microsemi® recommends Plan B, C or D. Plan D works with all deployment scenarios and guarantees the phase and frequency needs at the edge for LTE and LTE-A. However, moving PRTC closer to the edge also means caution for the GNSS outages and having recovery mechanisms to keep critical networks up and running. Figure 9 illustrates how deploying Cesium can keep the network backed up.

To effectively move PRTC closer to the edge and simultaneously keep the network redundant and resilient from global postioning system (GPS) outages there are a few options for providing frequency and time/phase at the edge of the network.

Frequency can be delivered by associating GNSS/GPS with eNodeB or synchronous Ethernet (SyncE) or by having PTP flow from a grand master to the eNodeB. The key performance metric to be met when reconstructing frequency using PTP is the degradation of packet delay variation (PDV).

To deliver phase and time closer to the edge a few options are available: GPS/GNSS at eNodeB, PTP flow from GMC to eNodeB PTP slave. The GMC must have access to GNSS/GPS.

As discussed in the previous section, the transport network typically has inherent asymmetry that impacts PTP time/phase delivery. Therefore, the network, and in particular the sync chains, must be correctly engineered to reduce the asymmetry to the point where it no longer impacts the sync service. There are models available from sync vendors such as Microsemi that show how to compensate and mitigate network PDV and asymmetry to ensure phase/time delivery within the bounds of the ITU requirements.

Engineering PTP for frequency and phase is quite different. The deployment of BC is not recommended in G.8265.1 (frequency), which was specifically developed to transport timestamps over legacy Ethernet infrastructure that did not have embedded PTP clocks. However, for phase/time, boundary clocks (and transparent clocks, although not currently recommended in the ITU) can be deployed in the network elements to help reduce asymmetry and accumulated time error on the sync chain. G.8275.1 (phase) mandates the use of BC in every network element along with L2 transport only. The ITU is currently developing more sophisticated and flexible models for phase transport over L3 networks (G.8275.2).

Another key concept when engineering time and phase is that it must reference UTC. This is a requirement for overall network operation end-to-end. Therefore, the eNB must not be allowed to drift using an arbitrary phase. To ensure that functions such as interference mitigation, CoMP, MIMO, and so on operate correctly the same UTC time reference must be used consistently throughout the network.

ITU-T standard G.8275.1 calls for phase synchronization with full on-path support with embedded BCs. A detailed view of the trade-off between the G.8275.1 and G.8275.2 standards include:

- This method depends on rebuilding (increased capital expenditure) a new network that includes BC (boundary clock) in every network node element.
- This does not allow for network asymmetry generated due to transmission and switch node elements as described in the previous section.
- The ITU standard G.8275.1 describes the use of boundary clocks and a synchronous Ethernet chain to support delivery of accurate UTC time and phase to eNodeBs. As illustrated, the standard assigns error budgets to the network segments involved in the transport network between the PRTC traceable grandmaster clocks and the cell sites.
- These time error budget allocations are defined to ensure that time transfer error between the UTC source of time and phase does not exceed the time and phase transfer error specifications (+/- 1.5 µs to UTC time and phase) for the applications (LTE-A/LTE-TDD). The G.8275.2 standard also allows for engineering PTP delivery to eNodeBs within the +/-1.5 µs specification and is also constructed to address time transfer errors. Table 1 shows the comparison of the two ITU PTP profiles for time and phase synchronization.
- The ITU standard G.8272 outlines the specification for a UTC traceable reference for a grandmaster clock function called PRTC, where a PRTC must be within 100 ns of the UTC time. The reason for the error budget allocations in the above referenced standards is to establish a common and traceable time reference for all segments of the network to assure there is no interference at network segment boundaries. It is also important to establish a common UTC traceable reference for all clocks in the network to facilitate failover protection. In a master clock failover case, slave clocks switch to an alternate grand master clock to maintain their 1.5 µs accuracy requirement. If the alternate grand master clock is not also traceable to +/- 100 ns to UTC, slave clocks pull away to align to their new reference resulting in severe interference with their adjacent cells and degradation of service. This is why the ITU specifications require that all clocks in the network maintain traceability to PRTCs locked to +/- 100 ns of UTC at all times.
- If UTC traceable time and phase is not maintained in a cluster of macro cells or small cells other cell sites that overlap in coverage within the +/- 1.5 µs specification or are using arbitrary phase in the same spectrum will cause interference issues relative to the time slot assignments associated with the LTE advanced features such as eMBMS, eICIC and CoMP. The time and phase profiles for the ITU standards clearly define why arbitrary time and phase not traceable to UTC is not an option for LTE advanced and LTE-TDD deployments. The technology related to asymmetry mitigation such as boundary clocks and PRTCs are designed to ensure delivery of accurate and traceable UTC time and phase and should be deployed accordingly.

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Recommendation and Example Deployment

For networks that are already using G.8275.1 we highly recommend that they deploy GM closer to the edge to provide and compensate for network path asymmetry (Figure 11).

Microsemi also recommends G.8275.2 with assisted partial timing support (APTS).

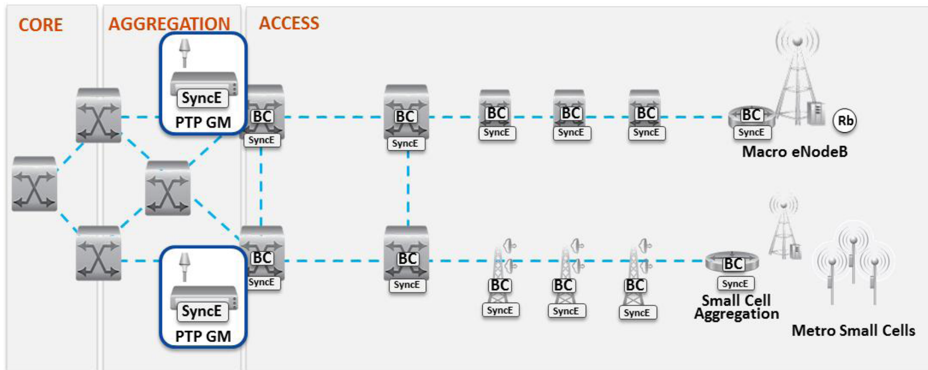

Figure 11. A G.8275.1 Network

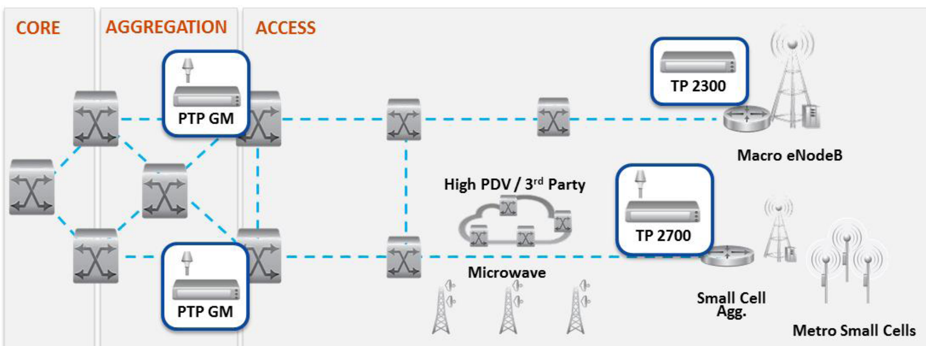

Figure 12. A G.8275.2 Network with Assisted Partial Timing Support (APTS)

G.8275.1 and G.8275.2 Standards Comparison

Table 1. G.8275.1 and G.8275.2 Standards Comparison

G.8275.1	G.8275.2	Comments
• SyncE through entire transmission path for stability. • Asymmetry may require hop by hop, manual measurement and entry of off-set factors to “calibrate out” hop by hop network path asymmetry errors. • No upgrade path from G.8265 fre-quency architecture. • Boundary clock on all transmission network elements.	• No change in network hardware • Operated over existing multiprotocol label switching (MPLS)/customer edge (CE) network • Preserves MPLS value proposition • No change to back office engineering and operations processes • Mitigates asymmetry as an issue • Sync not dependent on embedded network element (NE) • Can leverage existing PTP GM deployments • Can leverage existing GPS at eNodeB • Compliant to existing sync standards • Compatible with G.8265.1 profile • Simple and easy to deploy for all LTE architectures	Both ITU sponsored PTP profiles for phase and time synchronization are well engineered to meet the stringent microsecond level requirements outlined above. G.8275.1 is best suited to a Greenfield environment where new networks are being built from the ground up with full on path timing support (PTP boundary clocks and SyncE) in every network element. Potential drawbacks of the G.8275.1 model for carriers include costliness to upgrade all network elements to support PTP BCs and SyncE, and physical path asymmetry between hops may need to be manually compen-sated for. G.8275.2 is designed to operate over existing networks and leverage equipment currently deployed to provide frequency synchronization (G.8265.1) by adding UTC time traceability. Both 8275.1 and 8275.2 solutions require careful manage-ment and compensation of network path asymmetry errors to assure accurate synchronization is provided for target service requirements. A common engineering practice is to place PRTC traceable Time-GM clocks at or near the network edge to keep PTP hop count low, and limit build up of network path asymmetry errors.

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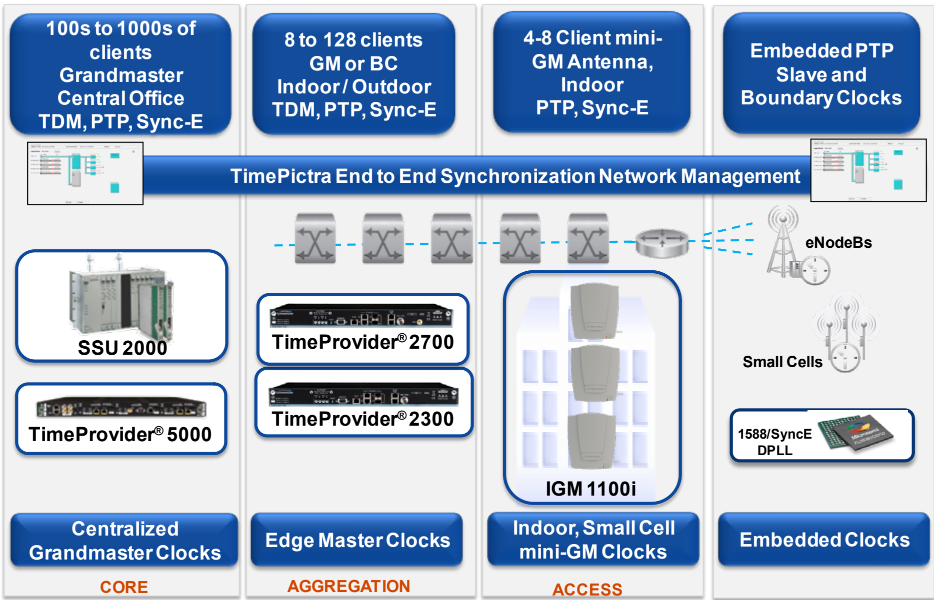

Figure 13. Microsemi's Complete End-to-End Timing and Synchronization Portfolio

It is important to note that both ITU profiles for PTP time and phase synchronization (G.8275.1 and G.8275.2) require that all clocks in the network maintain traceability to a PRTC with +/- 100 ns accuracy to UTC (G.8272). Common traceability assures networks can seamlessly scale up and interoperate as they grow and overlay in the HetNet model. If islands of arbitrary traceability are introduced, they may not be able to tie into the overall HetNet model and over time may result in interference due to lack of PRTC traceability.

Microsemi understands that networks are in a constant state of flux and is providing support and solutions as networks need to be upgraded from a previous deployment to address the challenges of a completely new network. We provide a complete end-to-end portfolio to address the timing needs for the entire network with flexible synchronization systems solutions, and comprehensive synchronization element management systems (Figure 13).

Summary and The Microsemi Value Proposition

Microsemi provides a broad range of PTP and SyncE solutions for the industry. Our clocking ICs are embedded in many base stations and network elements, and our flexible portfolio of PTP/SyncE master clocks makes it easy to deploy the right sized clock in the correct section of the network. Additionally, our industry leading TimePictra synchronization management system ties it all together with full end-to-end synchronization management visibility for critical network timing infrastructure.

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Microsemi Corporate Headquarters
One Enterprise, Aliso Viejo,
CA 92656 USA

Within the USA: +1 (800) 713-4113
Outside the USA: +1 (949) 380-6100
Sales: +1 (949) 380-6136
Fax: +1 (949) 215-4996

E-mail: sales.support@microsemi.com

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