Deploying Switches/Routers with Integrated Primary Reference Time Clock and Grandmaster Clock Functions: A False Economy

This use case studies the experience of Tier 1 operators around the world that deployed switches/routers with embedded timing functions to support phase-based LTE-A services.

Network element vendors have been promoting a hybrid solution that adds integrated timing, such as Primary Reference Time Clock (PRTC), Grandmaster Clock (GMC), and Boundary Clock (BC) capability, to their switch/router devices instead of deploying the more traditional high-performance, standalone clocks.

At first glance, this looks like a technically appropriate and cost-efficient solution; however, there are performance limitations with this implementation that give rise to significant problems.

The use case outlined here is a practical example of the disadvantages of this bundled implementation approach. It turned out to be a false economy.

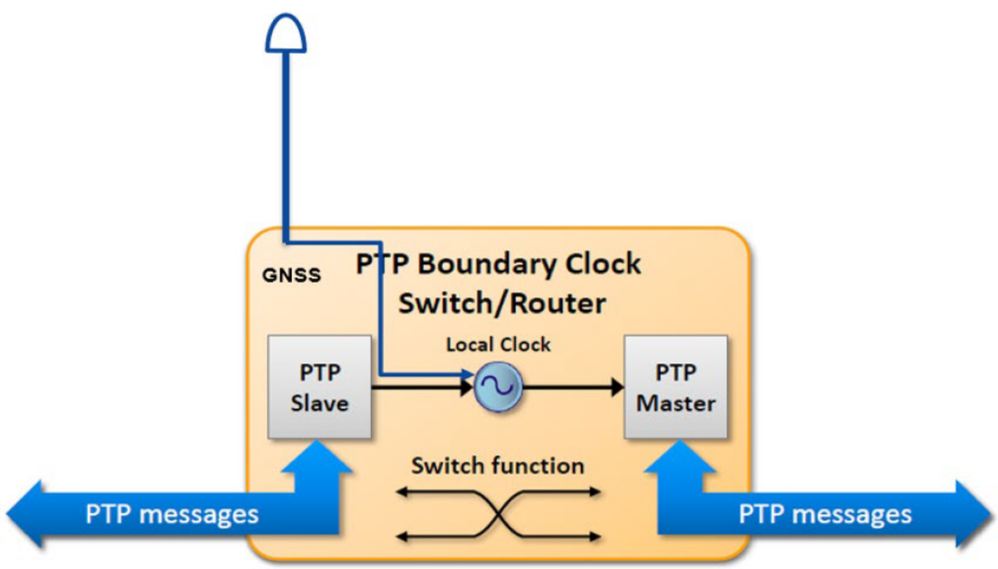
Network Element Architecture and Topology

The main task of a switch or router is to switch or route user data (packets) through the network. To differentiate from competitors and provide additional value, Original Equipment Manufacturer (OEM) vendors are adding timing functions such as GNSS, embedded Grandmaster Clocks (GMCs) and Primary Reference Time Clocks (PRTCs) to their devices.

However, switches/routers are designed mainly to handle user traffic, and the systems are therefore not necessarily engineered to consistently meet the strict time error budgets determined for the GMC when acting as a PRTC as per ITU-T G.8272.

The network element architecture and common network topology using a switch/router with hybrid capability to support embedded timing is shown in the following figure.

Switch/Router with Embedded Timing Functionality



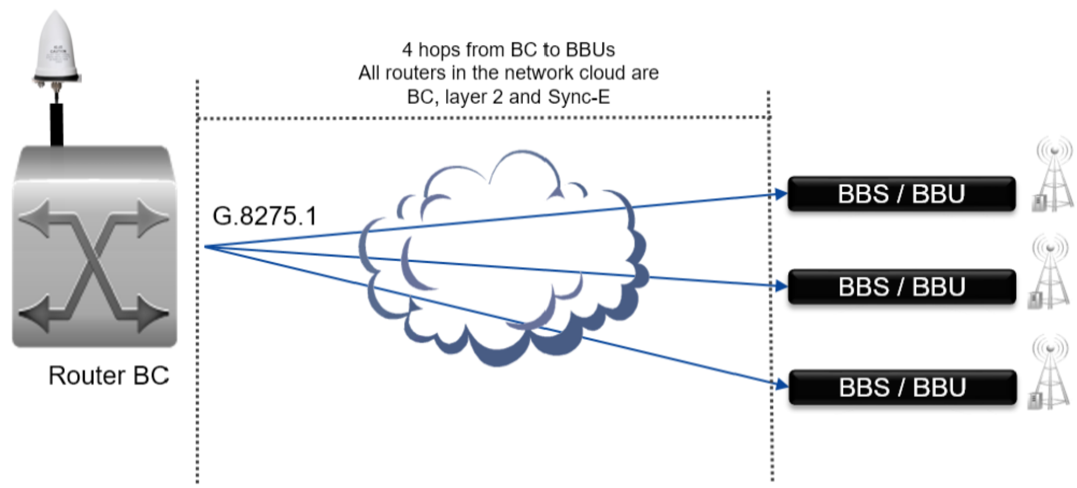
The timing functions can operate in two modes; first, as a GMC by adding a local GNSS antenna to the system; and second, when deployed without the GNSS, as a G.8273 Boundary Clock (BC) receiving PTP packets from a GMC deployed upstream in the network.

Some timing-enabled devices can also accept an external PTP input used to provide backup to the GNSS signal using a mechanism called Assisted Partial Timing Support (APTS, ITU-T G.8273.4). APTS effectively prolongs the local oscillator holdover time. Note that for APTS to work as required, the unit must first operate for a period of time with an active GNSS to enable the necessary calibration of the APTS-enabled PTP flow. In other words, there can be no APTS without a GNSS. The length of time that APTS can maintain oscillator stability, if the local GNSS is no longer available, depends on the quality of the APTS algorithm in the device and, critically, on the quality/performance of the oscillator used in the clocking system. The lower the oscillator quality, the shorter the holdover duration before the system violates a given output time error.

Implementation of Timing-Enabled Systems

The following figure shows a typical implementation of the timing-enabled switch/router. In all cases, the service providers were using a Multicast PTP profile (G.8275.1) at the edge of the network. GNSS antennas were installed on the switches/routers populated with a GMC/BC function, thus converting them into PRTC. The hybrid systems then generated G.8275.1 timing flows that were sent to all the eNB in the clusters connected to the node. The edge transport network was Layer 2 in all cases.

Deployment Scenario for Router/Switch with Integrated Timing



Main disadvantages of this approach:

- The BC/GMC-enabled routers cannot consistently reach PRTC quality as per ITU-T G.8272. According to this standard, the time output of the PRTC should be accurate to within ±100 ns or better when verified against UTC. However, when hybrid switches/routers are configured as PRTC (by adding a GNSS antenna to the unit), they often exhibit a high phase error, typically 2x to 3x the ITU-T maximum time error specification. This has two consequences: first, it requires the downstream Telecom Slave Clock (T-SC) to ignore the PRTC accuracy statement delivered in the G.8275.1 flow (in theory, if the PRTC is >±100 ns, the T-SC should reject that flow); second, assuming the flow is accepted by the T-SC, it significantly reduces the total Time Error (TE) budget allowed in the transport network. The overall TE is nominally ±1 µs (±1000 ns) maximum if, and only if, the PRTC is rated at ±100 ns. If the PRTC maximum TE is >±100 ns, then the TE budget for the network is correspondingly reduced. For example, if the PRTC flags ±300 ns (an additional ±200 ns), then the overall network maximum TE must be reduced accordingly from ±1000 ns to ±800 ns. Under these conditions, the reduced transport network TE budget will reduce the total number of hops (NE) allowed between the PRTC and the T-SC, potentially impacting the network architecture. The following figure shows the time error budget at each segment in a phase sync network.

Time Error Budget for Phase Distribution for LTE

Budget Component	ePRTC (G.8272.1)	PRTC (G.8272)	Holdover / Rearrange ments	Random Error + NEs error + Link Asymmetries	Holdover / Rearrangements	End Application
Time Budget	±30 ηs	±100 ηs	±200 ηs	±800 ηs	±250 ηs	±150 ηs

- All network paths from the BC/GM-enabled switch/router to the eNB (BBU) must be on a Layer 2 network where every NE has a Boundary Clock. Considering that BC-enabled switches/routers are more expensive than regular routers, the cost of this implementation is potentially much higher, compared to a Layer 3, IP/MPLS approach that can use standard asynchronous NE.
- BC/GM routers often cannot support any operationally viable phase holdover due to the use of very low-cost, low-performance oscillators inside the equipment. The result is that if the GNSS signal is lost, all eNB in a cluster attached to that switch/router lose phase synchronization, immediately impacting phase based LTE-A services, and, in a TDD environment, stopping service completely.
- Critically, a low-cost oscillator is unable to properly suppress jitter and noise (that causes wander) from the GNSS signal. Thus, the operators in the study all experienced constant GNSS signal loss events in their switches. The effects of these events in a frequency sync network (3G/LTE-FDD) are usually unnoticeable, but will typically affect service in a phase sync network, especially as certain LTE-A services (and future 5G services) require antenna alignment in the order of hundreds of nanoseconds.
- The network operator has no visibility into the status of the timing functions of the eNB connected to the switches, as they are not managed or monitored by a specialized synchronization management system. Operational consistency and awareness is needed for the end to end timing system as it gets more and more critical to ensure it is always on. Therefore, visibility of the timing instances is a requirement going forward.

- PRTCs must have holdover capability according to ITU-T 8271.1 requirements. The PRTC must maintain the phase error budget for holdover/rearrangements at <±400 ns during a GNSS failure to guarantee that all PTP phase clients won't lose the phase reference and such that the air interface will be stable in the absolute time error budget of ±1.5 µs. For best practices, hold the recommended time error for holdover at PRTC (±400 ns) for more than 24 hours.

PRTC Holdover Capability Requirements

Budget Component	ePRTC (G.8272.1)	PRTC (G.8272)	Holdover / Rearrange ments	Random Error + NEs error + Link Asymmetries	Holdover / Rearrangements	End Application
Time Budget	±30 ηs	±100 ηs	±400 ηs	±850 ηs	±0 ηs	±150 ηs

Result

The network operators studied for this use case experienced all the negative effects of relying on network elements with low-cost oscillators to provide phase sync. The consequences were that the LTE-A services were severely impacted.

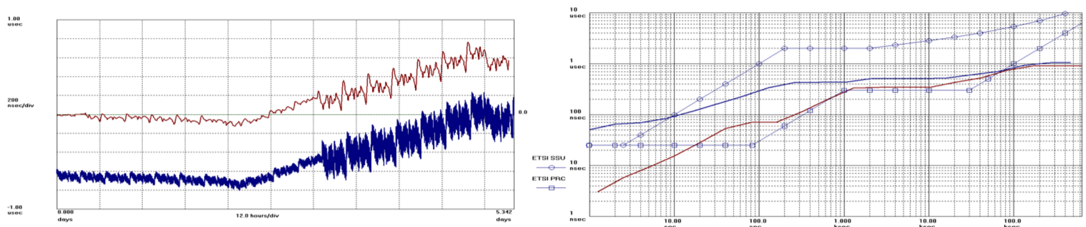
To deliver the LTE phase services required, they were forced to invest in an overlay network of additional standalone PRTC grandmaster clocks co-located with the NE that were originally supposed to deliver the timing service. Moreover, observing the impact on the network that resulted from the failure of the GNSS services, they also realized that it was prudent to back up all the newly deployed edge clocks with APTS links from upstream PRTC.

These changes were in addition to the ineffective original investment and added a layer of complexity and operations cost to the network that could have been avoided, for example, additional antennas, re-configuration of the network, addition of PTP paths, and so on. This significant extra cost was incurred simply to mitigate the impact on the network that resulted from choosing to deploy a poor-performance embedded timing function in the switches/routers. These operators were unfortunate examples of the law of unintended consequences: a (laudable) drive to economize led to more, not less, expenditure.

Further Considerations

1. When OEMs advocate architectures that use hybrid timing solutions, they often claim that SyncE can stabilize the oscillators used in the BC/GM clocks that populate the NE, but tests show that, while SyncE can work for frequency, this is not necessarily true for the distribution of phase timing. The main problem is that the low-performance oscillators used in the NE cannot efficiently filter network jitter and wander, and this failure seriously impacts the distribution of the phase signal across the network. The following figure shows an example of this performance.

   Impact of Low-Performance Oscillators on SyncE and Phase Transport

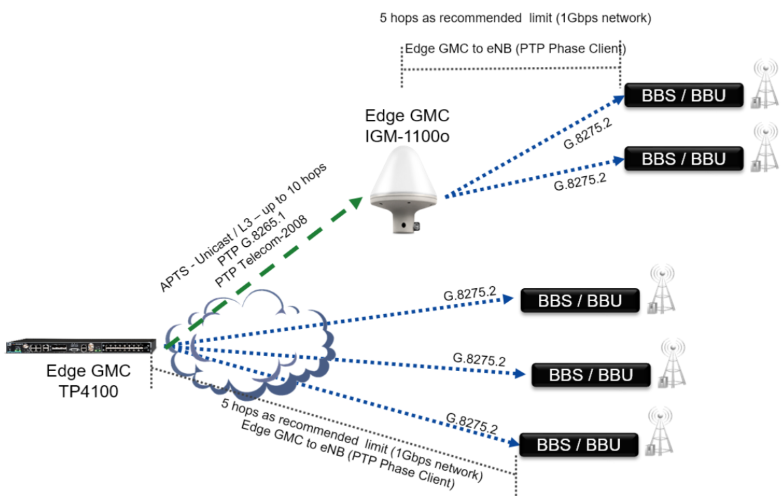
   Note: Jitter and wander on a SyncE/TDM backup will directly show on a grandmaster when in holdover.
2. At least one dedicated PRTC is needed in all cases, for two reasons. First, the GPS enabled switches/routers need an external signal source to provide a backup PTP flow (to feed the APTS as a solution in the case of GNSS failures). Second, simple BC-only routers (with no GNSS receivers) do not have holdover for phase and do not have a UTC reference. Therefore, the cost of the centralized PRTC clock is typically already in the project.
3. Dedicated PRTCs comply with the ITU-T G.8272 requirements of ±100 ns of phase error to UTC. The operator is therefore able to use all the phase TE budget (±1 µs) assigned for the transport network. This increases network design flexibility and may help reduce cost.
4. PRTC must have a holdover capability to prevent GNSS failure from causing the end application clock (eNB) to immediately enter holdover or simply stop providing service. For best practices, hold the recommended time error of <±400 ns for more than 24 hours. The oscillator in the eNB, or, even more critically, in the timing-enabled NE serving multiple eNBs, will typically be unable to deliver this level of performance.
5. In addition to a relatively high-quality oscillator, PRTC deployed at the edge of the network should ideally support APTS (G.8273.4). Dedicated PRTCs are typically designed to receive a PTP input from a PRTC located upstream in the network, which can be configured as APTS and act as backup to the local GNSS. The APTS algorithm from Microsemi allows the edge PRTC to guarantee a phase error within the ITU-T recommendations (less than 400 ns) for at least one week. Moreover, the Microsemi PRTC monitors and stores time error corrections for up to 32 network path changes between the source PRTC and the onboard PTP client in the receiving clock, thus protecting the system against the dynamic upstream network rearrangements typical in OTN and MPLS networks.
6. A new class of grandmaster PRTC, PRTC-B, has been defined with an accuracy of ±40 ns at the PTP output. This further increases the need to implement a tightly controlled timing environment in the timing function, with low noise chipsets and higher performance (more stable) oscillators. More importantly, if a NE is deployed with a classical PRTC rated at ±100 ns, it severely limits the ability/flexibility of the operator to subsequently migrate to the more precise PRTC-B independent of a switch/router upgrade.
7. Upgrade of embedded timing functions, for example making changes to meet the developing 5GNR or 802.1CM TSN requirements, depends on the upgrade schedule of the OEM switch/router. OEM switch vendors are reluctant to upgrade systems to add new service features unless they can generate more revenue from the operator and this can add significantly to operator costs. Moreover, new switch/router functions and the timing functions required, are not necessarily in lock step. For example, in 2019 it is expected that a new version of PTP (IEEE1588v2.1) of G.8273 (Boundary Clock class D) and an enhanced SyncE will all be released, but OEM will not want to disrupt ongoing engineering projects based on existing hardware to change timing functions, especially as the latter are not fundamental to the switch/router revenue stream.

8. Disaggregating the functional components, such as synchronization and signaling, from the data (user) traffic to enable a flexible network architecture is important to accelerate innovation in the network and meet the performance expectations of the evolving SDN/NFV networks, such as 5GNR and TSN IEEE 802.1CM. Therefore, it makes sense to separate the timing and data handling functions and to implement them in separate systems.
9. The heat of the switch/router chips and high-speed ports may negatively impact the performance of the oscillator if the latter does not have the correct cooling mechanism. Moreover, the noise of fans that switch on and off as heat accumulates can also negatively affect the oscillator. This is especially important when the S/R as high performance 25GE, 40GE, or 100GE PHY that run relatively hot.
10. Connecting a GPS or GNNS antenna directly to a switch or router creates additional risk associated with lightning. If a lighting strike enters the GPS receiver components, the strike can damage some or all the modules and line cards in the device with the common power traces being the most vulnerable. In the past, the Bell company engineering standards required the GPS receiver to be a separate shelf from the SSU BITS systems due to the possibility of a lightning strike causing damage where mission-critical timing feeds could be compromised. The same holds true for a switch or router where a lightning strike could cause interruption to traffic flows and services including e911 services. The practice of connecting a GPS or GNNS antenna directly to a switch or router is not recommended from a best engineering practice for timing systems and operators should be aware of the additional risk factors when considering this practice.

Deployment of PRTC for Phase Distribution Using Layer 3/MPLS

The following figure shows an alternative to the Layer 2 deployment model dependent on integrated BC. Here, there is a robust network topology using the unicast PTP phase profile G.8275.2, in a fully transparent IP/MPLS Layer 3 network.

Phase Distribution over Unicast PTP/Layer 3



Advantages of the Overlay Model

1. There is no need to re-engineer the core network to accommodate L2 boundary clocks. This is a major factor as core networks tend to be MPLS over OTN/DWDM.
2. Standalone clocks have no issues associated with low-performance oscillators noted above. Moreover, the operator can choose the oscillator quality in line with the service and holdover requirements of the application and location of deployment. For example, in locations where the PRTC is configured to serve many hundreds of eNBs, it is advisable to deploy a high-performance Rubidium-based system resistant to GNNS loss even without APTS. In locations where the PRTC serves only a few eNBs, it will be sufficient/more economical to deploy an OXCO-based system.

3. As the network requirements change and evolve, and in particular, as synchronization requirements and standards change with the evolution of 4G to 5G, it is far simpler and economical to change out a small form factor standalone clocking system than to change the whole network NE infrastructure.
4. Management and monitoring of the timing system is likely to be at best an afterthought, and more probably non-existent when the clocking implementation is embedded into the network transport. Deployment of a standalone timing infrastructure with sophisticated management software that can be deployed in an NFV to provide the operator with continual monitoring and management for quality and performance of the clocks in the network, including for eNB slave clocks, will be critical as we move towards always-on phase based 5G networks. Microsemi TimePictra is able to collate information from every clock in the network, even third-party (non-Microsemi) time slave clock implementations.

Comparison of Embedded PRTC/GMC and Standalone Clocks

The following table compares GNSS-enabled switch/router systems and the dedicated PRTC/GMC. It is elegant in terms of impact on service between the two different implementations.

Embedded versus Standalone Approaches to Clocking Systems

Parameter	GNSS-Enabled Switch/Router	Dedicated PRTC/GMC
Oscillator quality	Poor	High
Oscillator holdover for phase	Zero	40 hours
APTS architecture	Some	Yes
APTS stability to hold phase	2 days	>1 week
PRTC compliance	No	Yes
TE budget left for transport network	700 ns–500 ns	1000 ns
GNSS vulnerability	High	Low
OPEX costs	High	Low

Summary

This use case illustrates how switch/router elements, designed specifically for data transport and fast data-handling services, are not necessarily engineered to simultaneously provide high precision clock services. The simple addition of a BC SoC and a GNSS antenna to a switch/router is far from sufficient to provide such high-precision services.

The operators in this study, having experienced the poor performance and operational constraints inherent in the use of integrated timing solutions offered by the switch/router OEM, were forced to deploy an additional overlay of standalone PRTC at additional cost to provide the required phase services.

The investment of scarce resources in the embedded clock systems was originally seen as a low-cost alternative to the proliferation of PRTC/grandmaster clocks required as LTE-A services continue to expand at the edge of the network. However, instead of generating cost savings, these decisions caused the operators significant additional expense both in CAPEX and OPEX, that could easily have been avoided if good sync practices had been followed from the outset.

As mobile networks move steadily to phase-based advanced services for both LTE-A and 5G, networks will require an increasing number of dedicated PRTC/GMC clocks as a source of PTP to provide the timing services to the remote radios and to protect the eNB in the case of GNSS failure in the switches. Operators would be wise to avoid the false economy of the integrated PRTC/GMC solution when designing and engineering the network for high-availability, next-generation 4G and 5G mobile services. Utilizing a sophisticated end-to-end management system such as Microsemi TimePictra to monitor the quality and performance of clocks in the network is also key for reliable 5G performance.

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