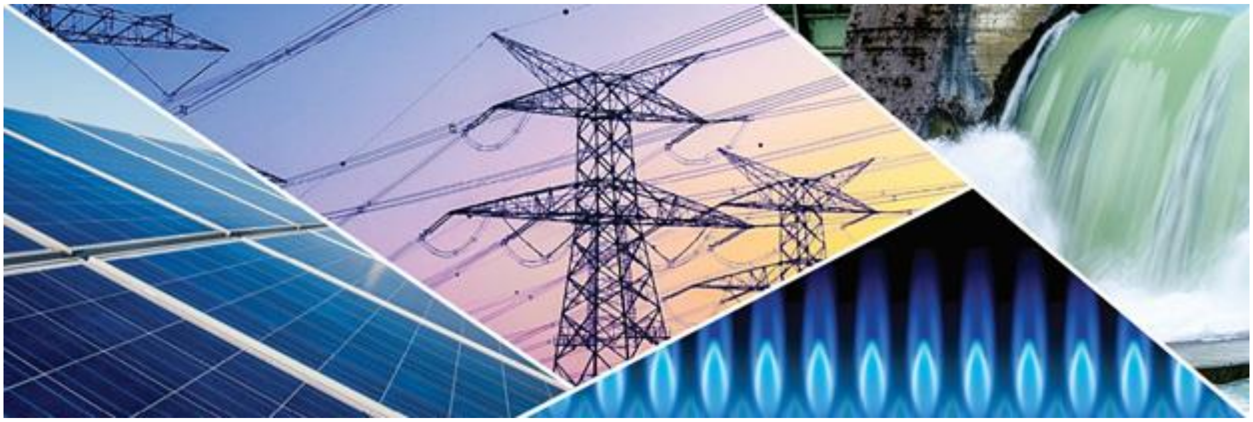

Utilities Technology Council™

# Keeping Time: The Future of the Network

## Modernizing synchronization architectures to meet the frequency and time requirements of a modern-day utility company

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A sea-change is in full swing in the utilities market. As a result of the generational changes that are impacting telecom networks seeking increased bandwidth, security and more, older utility equipment is no longer adequate to support the industry-wide shift to packet-based timing. While efficiency is increasing with the various applications being introduced, the infrastructure of the networks has not seen much change in the last few decades.

TDM-to-Packet, MPLS-TP, Private LTE and 5G are just some of the new buzz words and emerging technologies that are rapidly changing the telecommunications landscape of utilities, all requiring precise time synchronization. The good news is that there are solutions to help companies keep pace with the updates.

The following is a list of relevant considerations driving utility companies worldwide to sit up and take notice of current synchronization architectures that are not engineered to support new timing technologies.

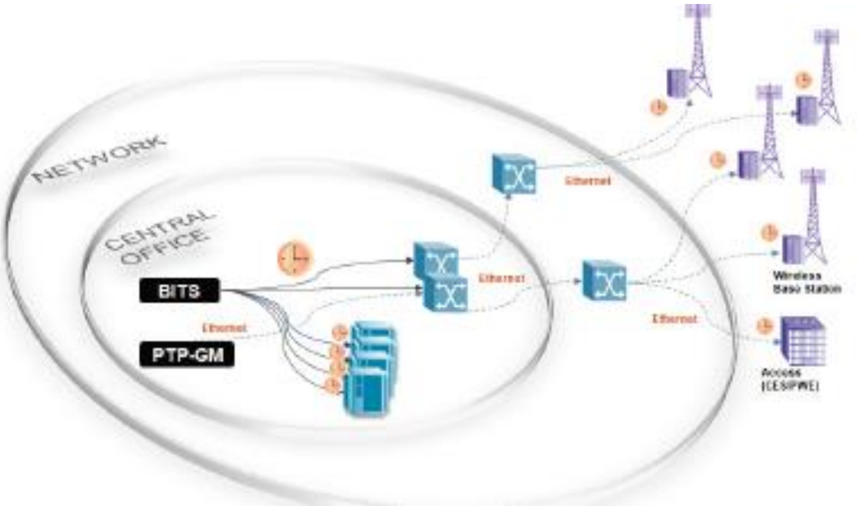
- Network Evolution (Transport) – Carrier Ethernet, MPLS, MMW-Radio
- New timing protocols – IEEE-1588v2 and Synchronous Ethernet
- Wireless (5G, Private LTE)
- Fixed Wireless
- Digital Substation Timing
- Mitigating Global Navigation Satellite System (GNSS) Vulnerabilities

Just as the telecommunications, datacenter and substation architectures are changing, so too are the technologies and equipment for synchronizing these networks. It is essential to move beyond the obsolescence of legacy timing systems and on to the technical and operational considerations for modernizing legacy network synchronization systems. This paper highlights some critical drivers for sync modernization, provides critical insight on what is important about these modern technologies and outlines simple solutions to modernize your synchronization network.

## NETWORK EVOLUTION - TIMING IMPLICATIONS

Figure 1 is a simple network representation showing a Building Integrated Timing Supply (BITS), a Precision Time Protocol Grand Master Clock (PTP-GM) and sync trails from the core across the network, to applications that require synchronization. The tiny clock faces represent an application requiring synchronization. In the TDM world, frequency synchronization is achieved by placing GNSS at each of these locations or distributing a stratum-1 traceable DS1 inside the office and across the TDM transport media.

Figure 1: Timing implications for Evolution.



The BITS is the source for stratum-1 timing. A Cesium primary reference source has been a common stratum-1 frequency standard. GNSS is the most prevalent source for stratum-1 frequency and time synchronization.

The requirement for synchronization does not disappear when the TDM transport is replaced with packet-technologies. However, the methods for providing network synchronization have evolved to new protocols such as Synchronous Ethernet (SyncE), Precision Time Protocol (PTP) and PacketPRS. Table 1 provides a description of legacy and new synchronization strategies.

*Table 1: Synchronization Strategies*

| | | |
|---|---|---|
| E1/T1 Circuits | Only applicable to TDM Networks | Frequency Delivery Only |
| ACR | Vendor specific proprietary solution to support TDMoIP | Frequency Delivery Only |
| GPS/GNSS | Reliable performance supporting a wide range of applications. Cost, vulnerability and maintenance issues limit wide scale use for time applications | Frequency & Time/Phase Delivery |
| Synchronous Ethernet | End-to-end physical layer frequency distribution scheme like line-timing | Frequency Delivery Only |
| IEEE-1588v2 PTP | Layer 2/3 protocol for delivery of frequency or time | Frequency & Time/Phase Delivery |
| PacketPRS | 1588v2 profiles enabled the delivery of frequency and time over IP networks | Frequency & Time Delivery |

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Different PTP profiles for different synchronization strategies

1. Frequency Synchronization - Telecom-2008 | ITU-T G.8265.1
    a. Circuit Emulation
    b. Wireless Backhaul – FDD. Pre LTE-A and 5G.
2. Time/Phase Synchronization – ITU- -G.8275.1 | ITU-T G.8275.2
    a. G.8275.1 – Full on path support. Requires network overhaul for boundary clock in every hop. Predominately utilized internationally.
    b. G.8275.2 – Partial on path support. Core PTP grand master w/GPS and Edge PTP grand master w/GPS. Enables the use of Assisted Path Timing Support (APTS), or asymmetry correction. Required in most US markets due to use of alternate access vendors who provide backhaul.

The migration of network technologies is likely to occur over many years, leaving the utility operating a hybrid network.

Thanks to large-scale migrations occurring in the telecom industry off TDM services and onto packet services, utilities have had to be flexible in following the changes while also adhering to the lengthy timelines needed for various stages of design, approval, and installation. For utilities with large networks, migration is a multi-stage process that will require the utility to function using a hybrid network that employs both old and new technologies. The conversion will evolve over time and across multiple engineering projects.

The physical layer DS1 timing requirements will continue shrinking while at the same time the need for modern synchronization protocols will increase to support numerous Ethernet-based appliances delivering a variety of services and applications.

## NEW TIMING PROTOCOLS AND TECHNOLOGIES

**Synchronous Ethernet**. SyncE is a physical layer synchronization scheme that enables the ethernet physical layer to be traceable to a stratum-1 primary reference source, much like line-timing SONET/SDH. The industry standards for the implementation of SyncE are found in the following ITU-T recommendations:

- ITU-T G.8261
- ITU-T G.8262
- ITU-T G.8264

Ethernet clock requirements are to be within +100 ppm; however, SyncE minimally requires phase-locked-loop clock circuits that meet a much tighter specification of +4.6 ppm.

The key operational considerations one must know about SyncE in terms of network planning are:

1. SyncE is a synchronization scheme that provides *frequency lock only*.
2. SyncE requires a SyncE capable switch or router at every hop in the synchronization trail. For the operator this means an end-to-end network upgrade not once, *but every time there is a new hardware or software release*.
3. As with any synchronization scheme, the cascading effect of distributed timing signals is a degradation of the signal in the way of jitter and wander. Figure 2 models and compares ITU guidelines for timing distribution.

*Figure 2. Comparison of ITU timing distribution model*

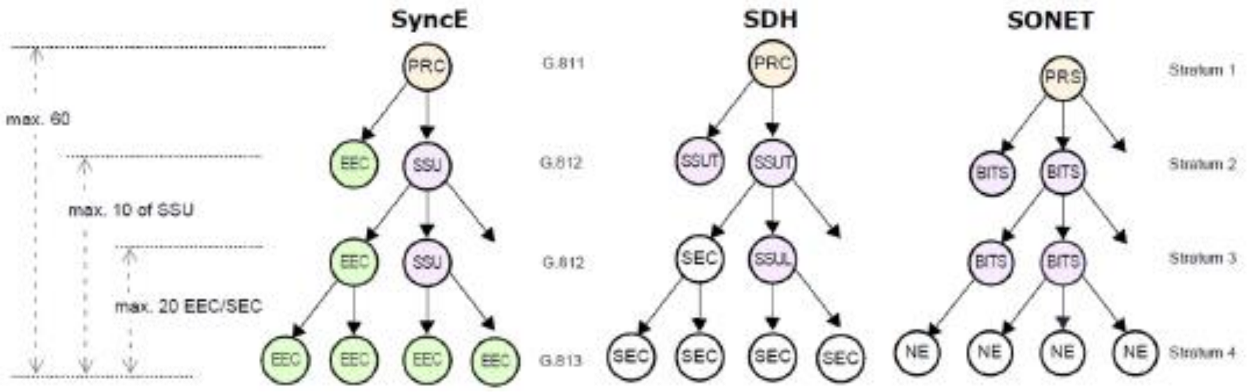


**Table Definitions:**
EEC – Ethernet Equipment Clock
SEC – SDH Equipment Clock
SSU – Synchronization Supply Unit
SSUT – SSU Transit. The SSUT is usually connected to a PRC and is used to sync other SSU's or nodes downstream. The SSUT should have a high-quality stratum 2 oscillator.
SSUL – SSU Local. The SSUL gets its reference from an upstream SSUT and is used to sync devices in a local node. The SSUL typically has a lower quality ST3E oscillator.

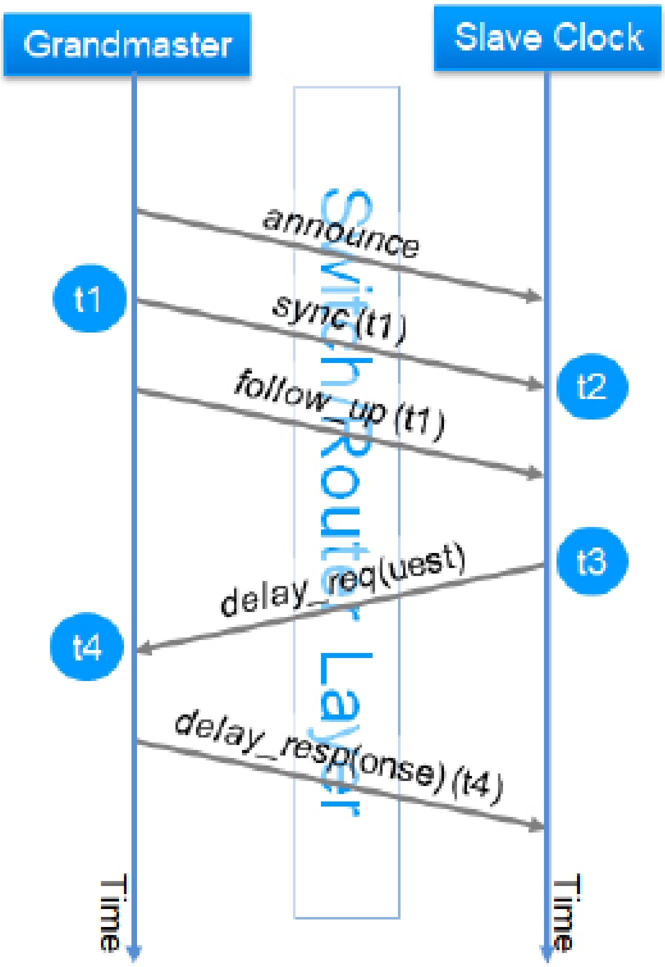
**EEE-1588v2, Precision Time Protocol.** PTP is a new standard adapted for telecommunications. There are currently four telecom profiles used for frequency or time and phase synchronization for network devices. Table 2 summarizes the telecom profiles.

*Table 2: Characteristics of IEEE-1588v2 Telecom Profiles*

| Attribute | EEE-1588v2-2008 | ITU-T G.8265.1 | ITU-T G.8275.1 | ITU-T G.8275.2 |
|---|---|---|---|---|
| Synchronization | Frequency Only | Frequency Only | Time/Phase | Time/Phase |
| Frequency/Time Spec | 16 ppb | 16 ppb | +1.5 is | +1.5 is |
| On Path Timing Support | None | None | Full | Partial |
| Messaging | Unicast (Layer3) | Unicast (Layer3) | Multicast (Layer2) | Unicast (Layer3) |
| Typical Application | Circuit Emulation<br>Wireless Backhaul-FDD | Circuit Emulation<br>Wireless Backhaul-FDD | 5G<br>LTE-A<br>Wireless Backhaul-TDD | 5G<br>LTE-A<br>Wireless Backhaul-TDD |

Precision is made possible in the PTP profiles through use of hardware-assisted time-stamping and the message exchange techniques. Figure 3 is an illustration for unicast message exchange. A series of signaling messages are exchanged to negotiate a lease agreement which is typically 1,000 seconds and negotiated continuously with the PTP-GM(s). The exchange of sync and follow-up (if two-step), delay request and delay response allow the client to calculate precise delay on the forward flow (A-B), reverse flow (B-A) and round-trip delay.

*Figure 3. Unicast Message Exchange Technique*



PTP has three principle elements – ordinary clocks (OC), transparent clocks (TC) and boundary clocks (BC). Ordinary clocks include the PTP-GM and PTP client or slave (PTP-C). TC are switches or routers that pass the packets along and insert the operating stack delay created within the device. The PTP-C is then able to calculate the delay. TC is not common in telecom protocols. TC is, however, a required element for the power profile application in the substation. BC, on the other hand, is a switch or router that is a client on the input and master on the output. The BC locks to the upstream PTP-GM and becomes the master to downstream PTP clients. BC may be used in the profiles for frequency, but is not required to meet the frequency specifications in most telecom networks. The ITU-T G.8275.1 "full on-path support" profile does require the use of BC to meet the rigorous phase requirements associated with TDD wireless backhaul, LTE-A services, Private LTE and 5G. The ITU-T G.8275.2 "partial on-path support" profile eliminates the cost for BC and enables the ability to meet rigorous phase requirements using assisted partial timing support (APTS).

The cause of timing impairments in a packet network are different for frequency versus time/phase applications. Table 3 lists the attributes of packet networks that affect the ability of a PTP client to do frequency reconstruction or time transfer.

*Table 3: Packet timing impairments*

| Attribute | Description |
|---|---|
| Packet Delay Variation, PDV | • Jitter<br>• Causes of PDV include queuing delays, congestion, and routing changes<br>• Increases with number of network elements and load<br>• Affects ability of the client algorithm to do frequency reconstruction |
| Network Asymmetry | • Forward path and reverse path not the same<br>• Causes include SFP optics, rate changes, different fiber lengths<br>• Affects the ability of the client to accurately transfer |
| Prolonged Packet Loss | • Without qualified available backup the client internal oscillator will enter holdover<br>• *The holdover performance of the client internal oscillator greatly affects network integrity* |
| Packet Delay<br>Packet Loss<br>Packet Errors | • Not issues for packet timing protocols |

**Assisted Partial Timing Support.** APTS[2] was adopted by the ITU-T and consented in Recommendation G.8273.4. In this architecture, the incoming PTP flow is time stamped by the GNSS used by the core PRTC. The PTP flow from the core PRTC to the edge PRTC is configured as a unicast protocol, G.8265.1 or G.8275.2. The PTP input is calibrated for time error using the local edge PRTC GNSS. This GNSS has the same reference (UTC) as the upstream GNSS. The incoming PTP flow can be considered effectively as a proxy GNSS signal from the core with traceability to UTC.

If the edge system GNSS now goes out of service for any reason, the edge PRTC can fall back onto the incoming calibrated PTP flow as the timing reference and continue to generate outbound PTP time stamps that are aligned with GNSS. This is illustrated in Figure 4.

*Figure 4. Assisted Partial Timing Support*

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[2] MSCC-0104-WP-01009-1.00-1118, White Paper: Assisted Partial Timing Support (APTS), November 2018

**Best Master Clock Algorithm.** The BMCA is an algorithm that helps the PTP-client choose the best clock source between two or more available PTP-GMs on the network. The BMCA only considers the self-declared quality of clocks and does not take into consideration the network link quality. Therefore, networks should be engineered so that PTP-clients do not select a GM clock in a location with excessive network asymmetry. Two examples of BMC algorithms are shown below. In the first example, user preference of GM selection is established with the GM priority 1 rule. The second algorithm places the actual reported GM performance ahead of user preference.

1 - GM priority 1↓
2 - GM clock class ↓
3 - GM clock accuracy ↓
4 - GM clock variance ↓
5 - GM priority 2 ↓
6 - GM identity

1 – GM clock class ↓
2 – GM clock accuracy ↓
3 – GM clock variance ↓
4 – GM priority 2 ↓
5 – GM identity

## 5G, Fixed Wireless and Private LTE Networks

5G, fixed wireless and mobility technologies will be ubiquitous across all critical infrastructure including the power utility industry. It will be associated with Private-LTE for the telecommunications network for the power utility.

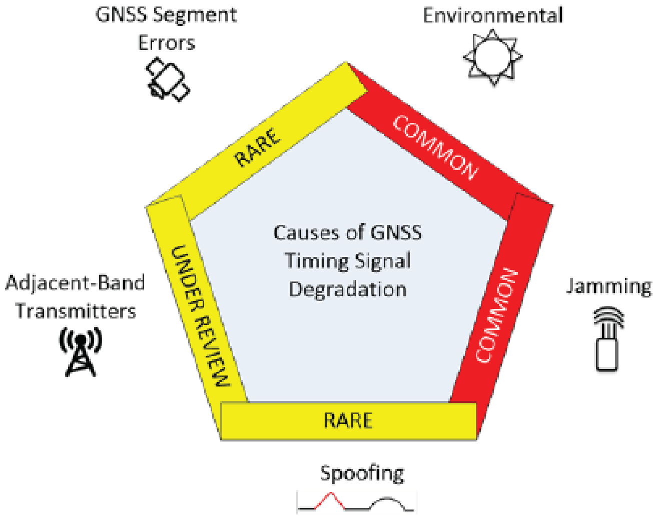
The uniqueness of the utility sector, however, compounds the obstacles slowing the adoption of mobility technologies. Those obstacles include, but are not limited to, densification, spectrum, security and policy.

For a deeper discussion on 5G, see *Cutting Through the Hype: 5G and its Potential Impacts on Electrical Utilities*, a white paper prepared for the Utilities Technology Council by the Joint Radio Company Ltd, March 2019.

## Mitigating Global Navigation Satellite Systems (GNSS) Vulnerabilities

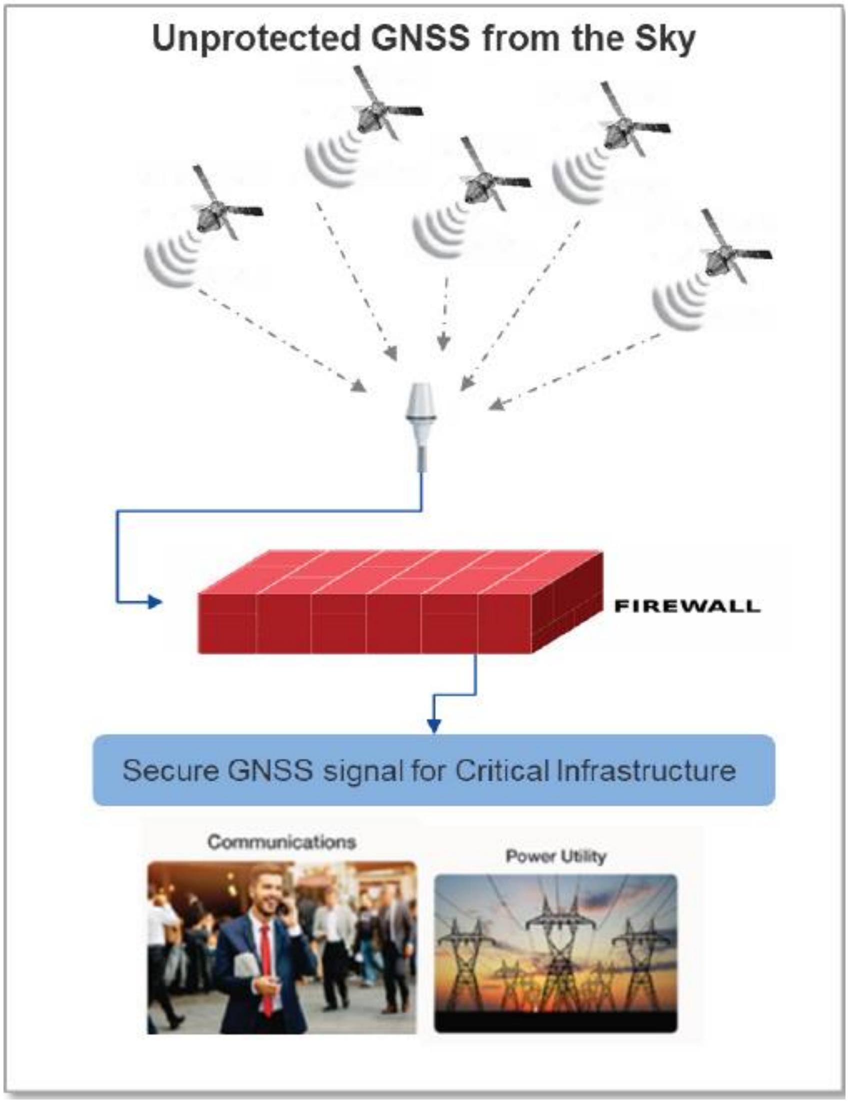
The dependency on Position, Navigation, and Timing (PNT) has become increasingly important to critical infrastructures such as communications, utilities, transportation, emergency services, financial services and data centers. This dependency has resulted from the ubiquitous availability and use of PNT from GNSS such as GLONASS, Galileo, Beidou, and others. To guide operators of critical infrastructure the Department of Homeland Security Science and Technology Directorate (DHS S&T) has published a best practices document that describes a range of steps that can be taken to mitigate outages and disruptions with GNSS reception, thereby improving PNT resiliency.

*Figure 5. Common Causes for GNSS Timing Degradation*



The idea of a firewall is common. One such technology now available is illustrated in Figure 6. The GNSS firewall sits between the "unprotected air" and the receiver. The firewall uses a set of rules to validate the integrity of the incoming GNSS signal. If the signal is deemed to be lost, impaired or corrupted, the firewall either squelches the output placing the receiver in holdover or provides a hardened output from a high-quality internal rubidium oscillator or stratum-1 autonomous timescale, like cesium.

*Figure 6. GNSS Firewall*



**Area Timing Hub**. The Area Timing Hub is another methodology utilized for mitigating GNSS vulnerabilities. The cesium primary reference resource is fundamental to the Area Timing Hub and provides a highly accurate and stable stratum-1 frequency reference to maintain frequency and time synchronization during GNSS outages.

Area Timing Hubs are beneficial when used to set time and/or back up time at remote locations, such as the substation. Before we go further with the discussion on the Area Timing Hub, we must first introduce new "time" related terminology. Table 4 lists time specifications for different classes of primary reference time clocks.

*Table 4: Primary Reference Time Clock specification*

| Time Clock | Description |
|---|---|
| PRTC Class A | A PTP-GM clock that provides output within +100 ns of UTC |
| PRTC Class B | A PTP-GM clock that provides output within +40 ns of UTC |
| ePRTC | A PTP-GM clock that provides output within +30 ns of UTC |

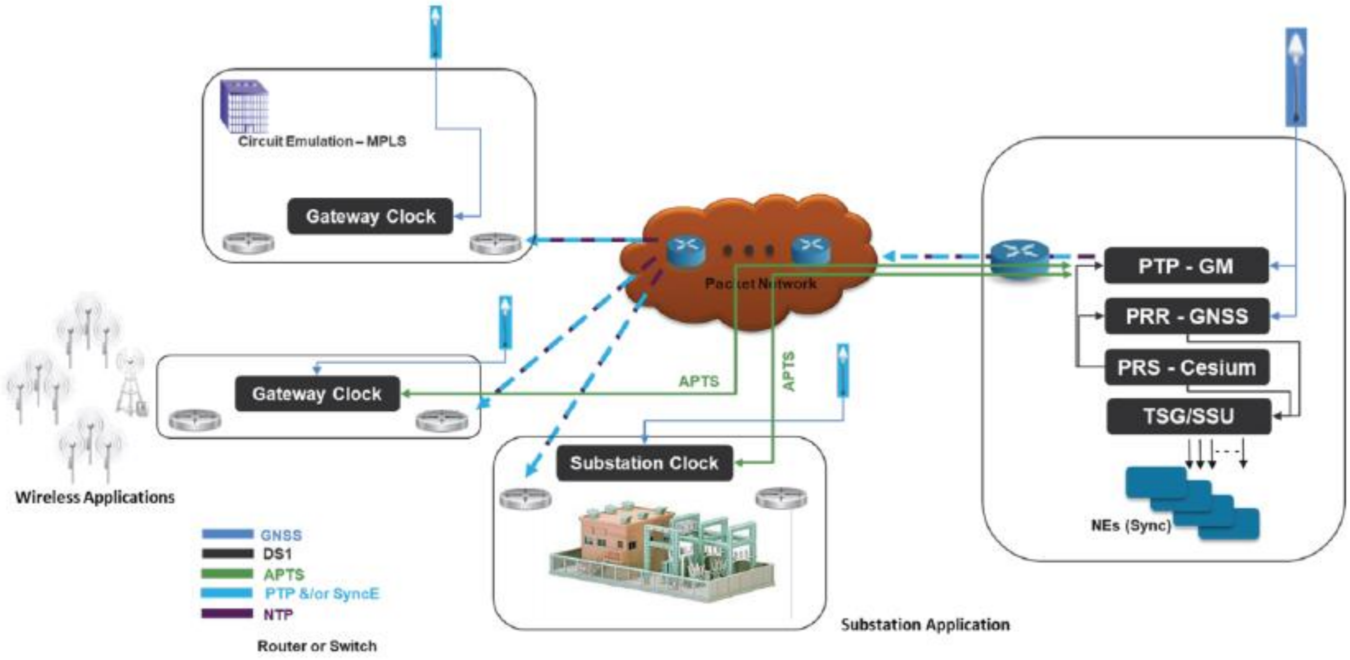
The PRTC is the PTP grand master or T-GM and there are different classifications for PRTC as shown in Table 4. To explain further, a common network error budget for TDD wireless applications is +1.5 microseconds. The operator can give back to the network +60 nanoseconds, simply by utilizing a Class B PRTC.

Figure 7 illustrates this idea of using an Area Timing Hub to provide alternative stratum-1 timing via PacketPRS technology. The Area Timing Hub on the right of the diagram includes a GNSS primary reference receiver, a cesium primary reference source, a SSU for local frequency timing signals and a PTP grand master from which frequency and time synchronization can be distributed in band across the MPLS/OTN/DWDM network – PacketPRS. PTP and SyncE may be used for frequency back-up to GNSS on radios, substation clocks and other IED's. PTP can be used to set time or as a back-up for GNSS on the edge. APTS may be enabled on an edge PTP grand master to enhance network time services.

The Area Timing Hub must have a cesium primary reference clock to back up GNSS for BITS and the PTP grand master clock. The Area Timing Hub should have an ePRTC and may also have a GNSS firewall.

The Area Timing Hub sets time with GNSS, maintains time with a good frequency source, and holds time with a high quality OCXO or rubidium local oscillator. The creation of regional timing hubs to back up GNSS with alternate timing standards – cesium, PTP or SyncE – protects the timing integrity of the network.

*Figure 7. Area Timing Hub, PacketPRS with APTS*



To better understand these concerns and ways to mitigate GNSS vulnerabilities, see The Alliance for Telecommunications Industry Solutions' technical report: ATIS-0900005.

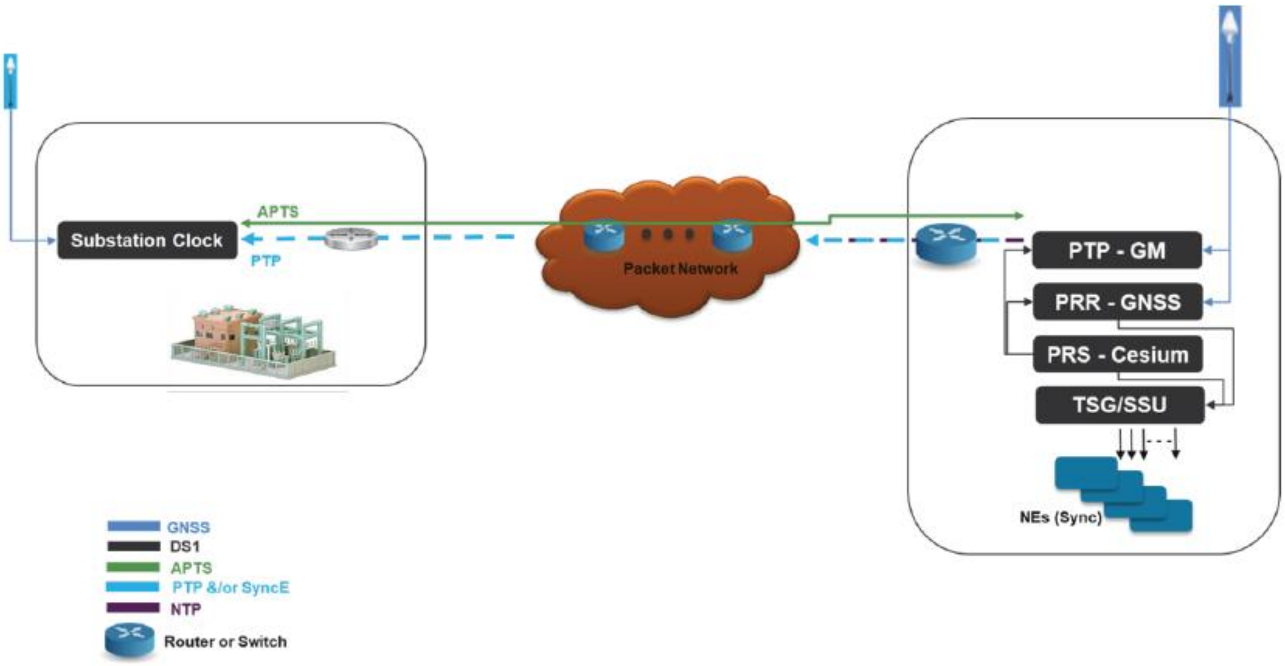
### Digital Substation Timing

Timing within the substation is slowly transitioning from analog to digital circuits, IRIG-B signals to one or more PTP power profiles with a strict timing requirement of +1 microsecond. The substation Ethernet LAN uses transparent clock functions in the switches to meet this timing requirement.

There are benefits for creating a bridge between the utilities telecommunications WAN and the substation LAN. This robust network architecture can increase accuracy and reliability in one of two ways.

First, PTP flows using APTS from Area Timing Hubs in the telecommunications network can be used as a backup to GNSS in the substation. This frequency backup prevents the substation clock from entering holdover and maintains the +1 phase requirement for an exponentially longer time allowing for restoration of the GNSS timing service. Figure 8 is a representation for this network topology.

*Figure 8. Utilization of Area Timing Hub, PacketPRS and APTS to improve high reliability and availability of the substation clock*



Network synchronization technologies are now allowing time to be set at the edge of the network from Area Timing Hubs with ePRTC features that eliminate the need for GNSS everywhere. In the future, a second method of increasing accuracy and reliability will be introduced via a translation device available in the substation and utilized to translate telecom PTP profiles into power profiles and IRIG-B analog signals.

### Sync Network Modernization

Once we acknowledge the need to modernize the synchronization network, the task of doing so may seem overwhelming. The following general steps are recommended for planning network modernization:

- Inventory current equipment and timing requirements
- Identify planned and future changes in the network and the timing prerequisites for new equipment and architecture
- Prioritize and replace or refresh, and augment existing timing systems
- Create regional timing hubs to secure the integrity and availability of timing services

The purpose, design and technology of legacy frequency distribution systems are not opportune to the new frequency and time synchronization of packet networks. These older systems may be replaced with current generation gateway clocks that are able to support both TDM and NTP, PTP, SyncE timing services required for new packet networks. Many utilities are deploying various types of packet networks (i.e., IP-MPLS, MPLS-TP, Carrier Ethernet, etc.) to replace their older SONET networks, which span across their service territories. Alternatively, older systems may be updated and augmented with the next generation gateway clocks that support packet timing services. To update refers to extending the life cycle of legacy systems with a software and hardware refresh to sustain the diminishing TDM timing needs in the network. Then augmenting these systems by overlaying a gateway clock that may act as a primary reference source to the legacy system while also introducing new timing protocols such as NTP, PTP and SyncE.

One example of augmentation would be to strategically select two or more regional offices and make them Area Timing Hubs. In these selected offices introduce a PRTC PTP grand master and cesium primary reference source. The cesium PRS provides highly accurate and stable frequency reference to back up GNSS in the legacy BITS, PTP grand master, and remote locations across the network. This augmentation of the synchronization network provides the highest level of reliability and availability for the overall engineering plan.

## Conclusion & Summary Remarks

This paper has explored the changing landscape for all utility companies and provided a birds-eye view of modern technologies and terminology that will follow us for the next 10 - 20 years. One thing is certain, change is happening and the technology and design of existing synchronization architectures are no longer capable of providing the timing services necessary today or the future.

The combination of Area Timing Hub and PacketPRS is a highly effective strategy for providing an accurate, secure and reliable timing service for the utility industry. While the outlook for the network over the next few decades is hazy, what is undeniable is the need for upgrades now. We must engineer our networks to support the most critical applications and services we intend to serve. Here, simple steps were presented to lead the industry from where it is to where it must go.