White Paper
Timing for cRAN Fronthaul LTE

Microsemi
Power Matters.™

Timing for cRAN Fronthaul LTE

Traditional 4G mobile networks have adopted a decentralized RAN architecture with baseband units (BBUs) physically co-located with remote radio units (RRUs) inside a base station (BS). The baseband processing includes physical (PHY) layer, media access (MAC) layer, and parts of the network layer processing performed inside the BS.

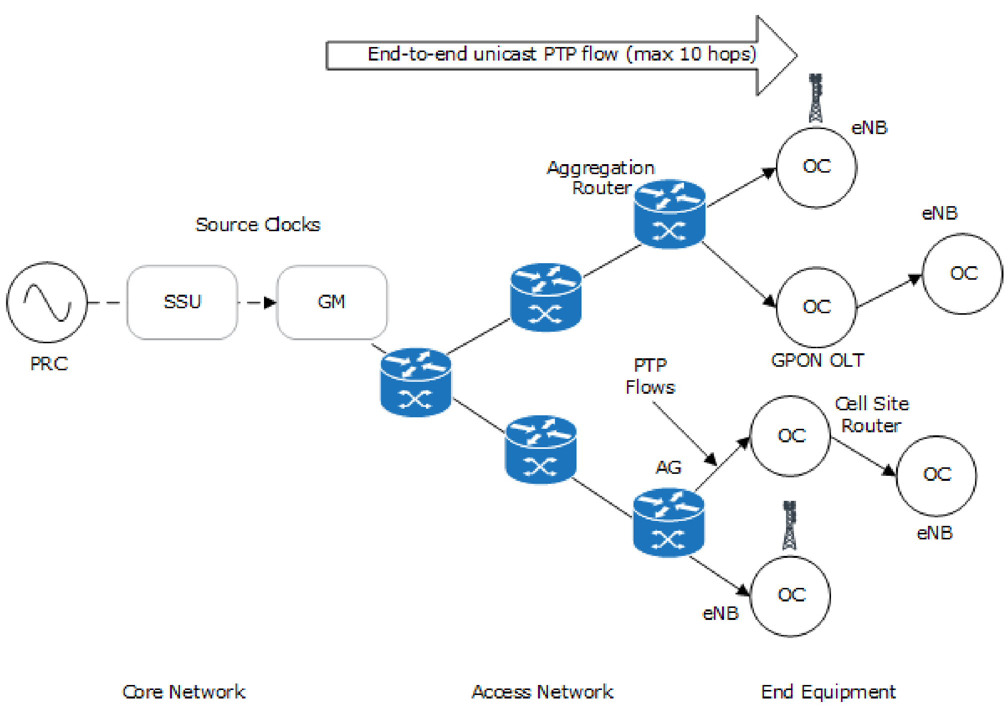
Mobile operators have begun to evolve their networks to prepare for 5G densification in major metro markets. Part of this evolution includes the migration from traditional mobile backhaul architectures to the concept of mobile fronthaul architectures. One of the major differences between backhaul and fronthaul is that fronthaul introduces the concept of segregating the baseband unit and radio head technologies in a cell site deployment. In mobile backhaul applications the cell sites include both the baseband unit and the radio head in the same location. These two technology functions communicate between them using a long-standing protocol called Common Public Radio Interface (CPRI). In mobile backhaul applications, this communication is executed over a short fiber optic cable of no more than a few meters.

5G has introduced a decentralized/distributed approach, called Cloud RAN (cRAN), which consists of centralizing the RAN functionalities in a broadband unit (BBU) pool location where the digital processing is performed. The remote radio head (RRH), which hosts the radio frequency (RF) transmit and receive components, performs analogue processing. In the cRAN architecture, the RRHs are connected to the BBU pool through high bandwidth transport links known as fronthaul.

In mobile fronthaul applications, the BBUs are pooled together in locations called cRAN hubs. These cRAN hub locations still use CPRI to communicate between the BBU and the RRH, but the distance of the fiber optic connection between the BBU and the RRH is a much greater distance—up to 17 km.

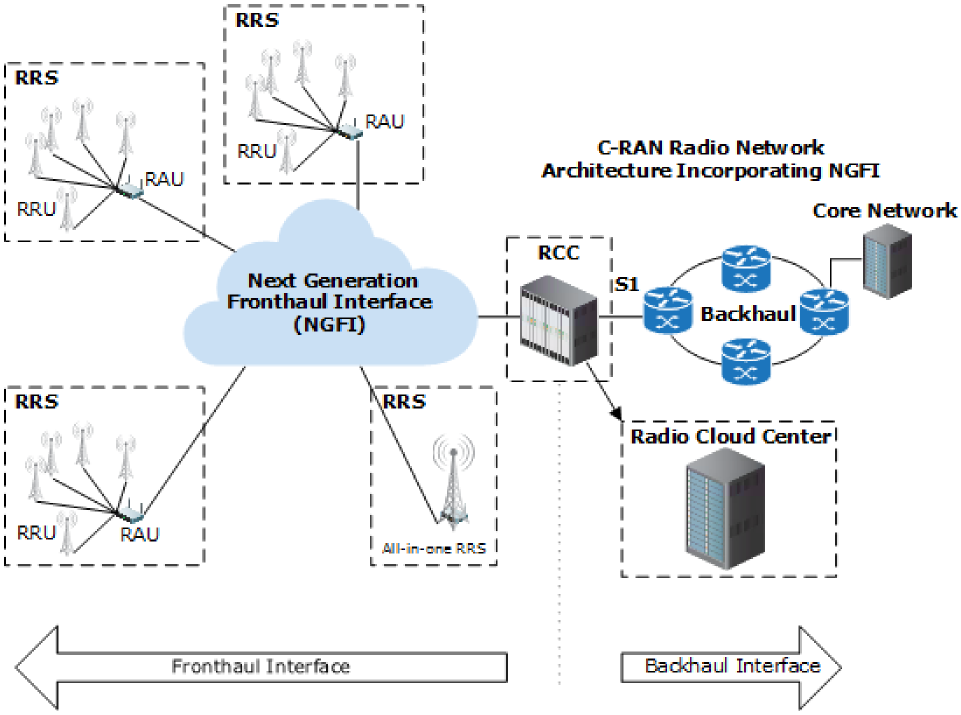
The following two illustrations show the mobile backhaul and fronthaul architectures.

Figure 1 • Mobile Backhaul for LTE Timing Architecture



Note: A grandmaster (GM) clock is a PTP server and an ordinary clock (OC) is a PTP slave/client.

Figure 2 • Mobile Fronthaul Architecture



The current mobile backhaul architectures in place today have alternative solutions for meeting the timing requirements (frequency, time, and phase) documented in the industry standards. These requirements are evolving to support the evolution from LTE to LTE-TDD and LTE-Advanced technologies.

The following two tables describe the LTE timing requirements defined by the industry standards organizations.

Table 1 • Why is Synchronization Required?

Application	Why You Need to Comply	Impact of Non-Compliance
LTE-FDD	Call initiation	Call interference Dropped calls
LTE-TDD	Time slot alignment	Packet loss/collisions Spectral inefficiency
LTE-A MBSFN	Proper time alignment of video signal decoding from multiple base stations	Video broadcast interruption
LTE-A MIMO /COMP	Coordination of signals to/from multiple base stations	Poor signal quality at edge of cells LBS accuracy
LTE-A eICIC	Interference coordination	Spectral inefficiency Service degradation

Investment in small cells and LTE networks is made to increase capacity and coverage. When synchronization fails, both objectives are lost. The resulting impact is felt by customers!

Table 2 • LTE Timing Specifications

Application	Frequency Network/Air	Phase	Note
GSM, UMTS, WCDMA, LTE-FDD	16 ppb/50 ppb	--	--
CDMA2000	16 ppb/50 ppb	±3 µs to ±10 µs	--
LTE-TDD	16 ppb/50 ppb	±1.5 µs	<3 km cell radius
		±5 µs	>3 km cell radius
LTE MBMS (LTE-FDD and LTE-TDD)	16 ppb/50 ppb	±5 µs	Inter-cell time difference
LTE-Advanced	16 ppb/50 ppb	±10 µs	In discussion by members of the 3GPP

Note: 5G phase alignment requirements for RRHs is to be decided. The current proposal is 260 nanoseconds (±130 nanoseconds).

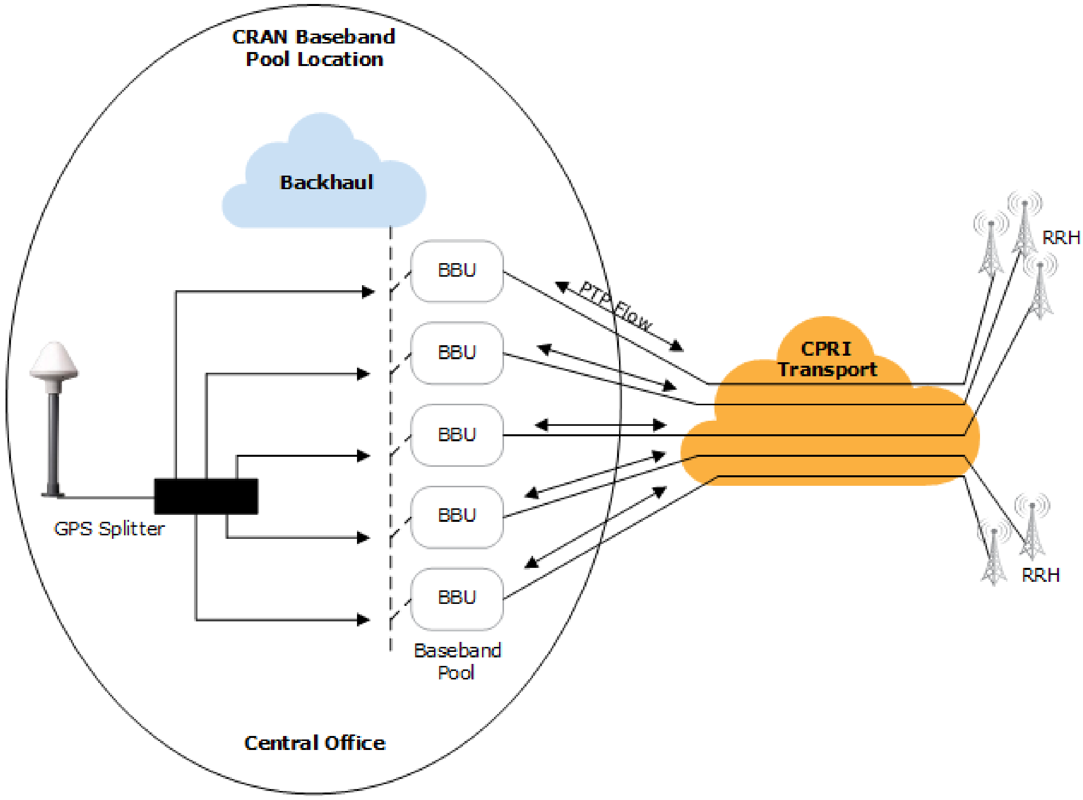
The timing requirements for LTE RAN applications is served by multiple technologies and in some cases timing solutions used for the primary timing reference are backed up by timing solutions used as the secondary timing reference. The following three solutions are currently deployed to meet the existing and evolving timing requirements in the RAN.

- Embedded GNSS receiver technology in the cell site baseband units. This provides for all three timing components (frequency, time, and phase) and support for location services in markets that require this support, such as e911.
- Precision Time Protocol (PTP), also referred to as IEEE 1588, that delivers timing using a time stamping mechanism over the transport and/or access network at layer 3 or layer 2. PTP introduces the concept of a grandmaster clock (GMC) and PTP slave or client that exchange time stamps to transfer time/phase and reconstruct frequency at the slave location, such as an eNodeB. PTP has two standards-based models used for deployment depending on the capabilities of the network elements support for PTP flows. PTP can be used as a primary or secondary timing reference.
- Synchronous Ethernet (SyncE) is a physical layer frequency distribution technology that can be used to distribute frequency in a chain of transport network elements in the same model used by SONET /SDH line timing applications. The drawback of SyncE is that it does not support time/phase transfer, only frequency.

There are several approaches to solving the timing requirements when using fronthaul- and CPRI-based timing mechanisms. Technical and business cases can be made for the various alternatives, but one of the most important considerations is a solution that can be positioned for both the short term and the long term that factors in the evolution aspects related to 5G densification. The alternatives and associated technical and cost considerations are listed as follows.

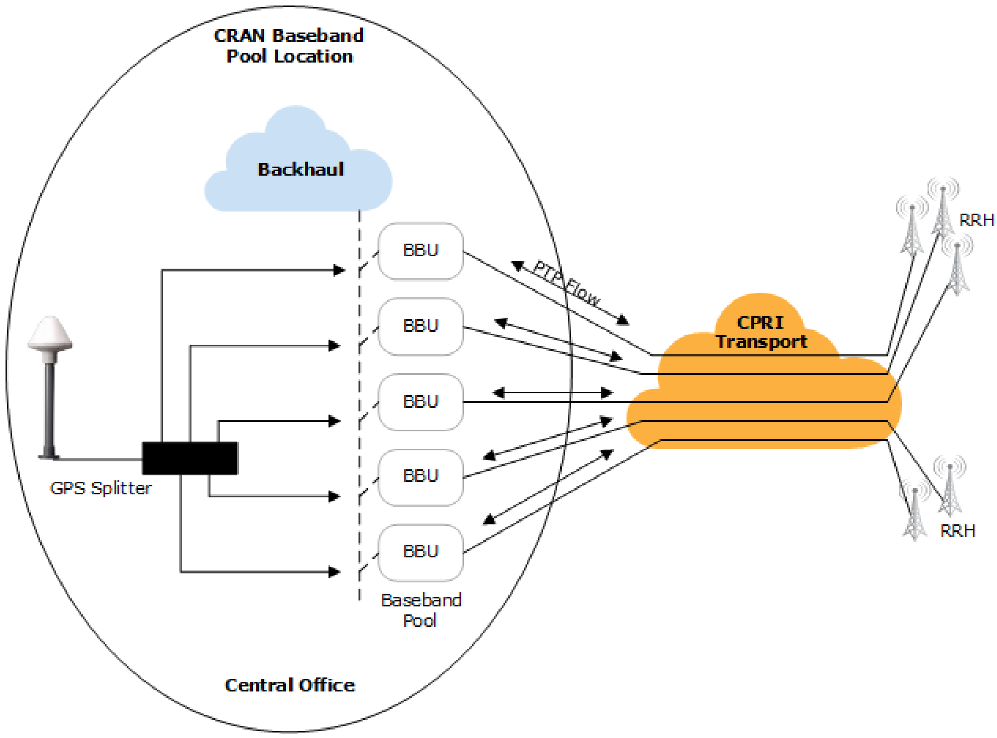
- GNSS L1 distribution using splitters to connect the antennas to the GNSS receiver inputs of the BBUs. The associated cabling can be expensive, and the disruption of the GNSS reception will result in the oscillators in the BBUs to revert their internal accuracy, limited holdover capability to maintain primary reference time clock (PRTC) 100-nanosecond to UTC accuracy, and drift apart at different rates and in either direction compared to the GNSS reference.
  The following illustration shows an example of GNSS L1 distribution.

Figure 3 • Example GNSS Splitter Distribution



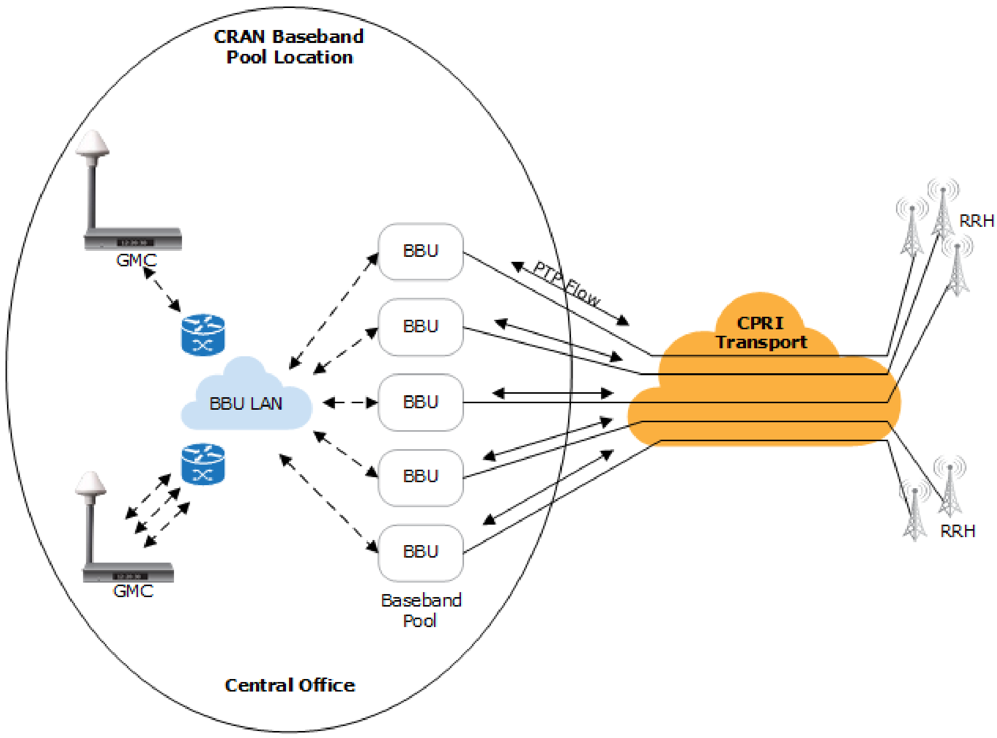
- GNSS receivers with a 1PPS output is daisy chained to BBUs to phase align the BBUs. This approach is fairly cost effective, but has a single point of failure issue, as a cable interruption can cause many of the clustered BBUs to revert to the internal oscillators in the BBUs with the same concerns as the previous approach.
  The following illustration shows an example of 1PPS distribution.

Figure 4 • CRAN CPRI Timing Use Case 1PPS (Single Point of Failure)



- Redundant GMCs connected to a GNSS reference that provide PTP flows thorough the LAN switch used to interconnect BBU traffic to PTP slaves in the BBU. This concept, in addition to being cost effective, provides the same accuracy level, 100 nanoseconds to Universal Coordinated Time (UTC), that a GNSS antenna achieves. This level of accuracy allows for Observed Time Difference of Arrival (OTDOA) support for e911 applications if needed. The LAN configurations for cRAN hubs should be redundant with two switches such that deploying two GMCs addresses single point of failure issues. The following illustration shows an example of GMC PTP distribution.

Figure 5 • CRAN CPRI TIming Use Case (GMC Redundant)

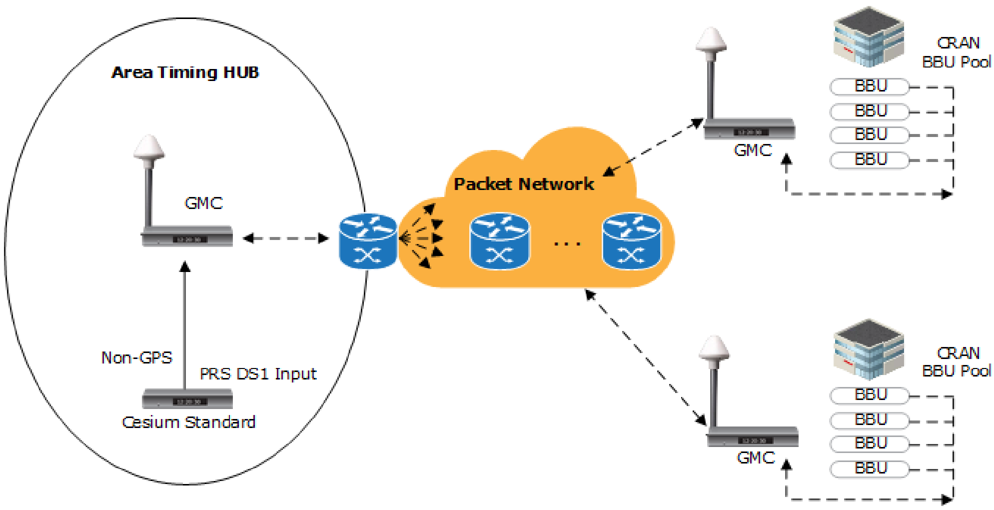


A technically-sound GMC solution requires at least one of the following attributes:

- Holdover using a Rubidium oscillator. A Rubidium oscillator will drift off from PRTC quality at a much slower rate than the internal oscillators of the BBUs if the GNSS reference is disrupted. All BBU oscillators following the GMC in holdover will be drifting from the PRTC accuracy at the same rate and in the same direction.
- A PTP input to the GMC from an adjacent facility using asymmetry compensation algorithms that can maintain time and phase if the PTP input is disrupted. PTP time transfer from an adjacent location introduces the concept of an area timing hub, which can be utilized as a backup location to several cRAN hub location GMCs. It is recommended that area timing hubs use a Cesium Standard Reference, in addition to GNSS, for protection in the use case of a wide area GNSS outage. In this use case, all cRAN hubs will follow the Cesium Reference and maintain phase alignment until the GNSS reference is restored.

The following illustration shows an example of an area timing hub.

Figure 6 • cRAN CPRI Timing Use Case (Area Timing Hub)



Looking to The Future: The Evolution to eCPRI, NGFI, and vRAN

As the mobile Telecom industry moves to 5G densification in major metro markets, the standards bodies and RAN vendors are busy preparing for the future. The high bandwidth and fiber requirements for the transport of CPRI are limiting the fronthaul deployments for many operators that do not have their own fiber assets. Traditional CPRI-based cRAN architecture uses dedicated fiber, which makes centralization an expensive solution because it involves a large number of fiber cores that are expensive to deploy. The transport of CPRI over the OTN, using DWDM, is one way some operators are scaling their CPRI deployments and in many cases these OTN assets are leased facilities.

There has been much debate over how to open the CPRI fronthaul market to all mobile players. The concepts of CPRI over Ethernet (eCPRI) and replacing the TDM-like CPRI format with Ethernet messaging both hold the promise of reducing the bandwidth requirements of CPRI transport and making fronthaul affordable and available to all mobile operators. Ethernet is a very cost-effective transport technology that is widely deployed in the backhaul transport network. However, it is also an asynchronous best-effort technology that has not been originally designed to meet the low latency, jitter, and synchronization requirements of baseband signal transmission.

These concepts fall under the Next Generation Fronthaul Interface (NGFI) umbrella, and it will be interesting to see if the industry moves to standardize on one format or adopt both methods. NGFI is the new fronthaul packet-based interface being studied by IEEE 1914.1 in order to provide a better bandwidth efficiency and achieve a more scalable transport networks. CPRI cannot scale with the bandwidth requirements of 5G.

With CPRI, the operations above the LTE stack PHY level are performed by the radio equipment controller (REC), which is also in charge of the radio signal generation. The radio equipment (RE) is responsible for the sampling of the radio signal in the uplink direction. In the downlink direction, it just reconstructs the signal before transmitting on the air interface. The RE performs minimal digital processing, making it possible to centralize most of the digital processing functions in the REC. CPRI defines a very strict synchronization requirement between the RE and the REC for time and frame alignment. The RE must be traceable to the REC clock with an accuracy of 8.138 ns. CPRI implements a bit synchronous mechanism, where new frames are transmitted every Tc= 260.416 ns. CPRI requires a clock jitter of 2 ppb (parts per billion, 4% of the total inaccuracy) and a round-trip timing accuracy of ±16 ns.

Both NGFI concepts would have an impact on the timing carried from a cRAN hub to the remote radio heads. As they are both Ethernet-based, not CPRI TDM, the timing will be impacted by introducing variable delays and asymmetry that was not present with CPRI over dedicated finer or the OTN. CPRI scales with carrier bandwidth and the number of antenna elements, which limits 5G features such as a massive number of antenna elements. The main approach that is being studied to remove the bandwidth requirement of CPRI fronthaul is to use various functional split options between the remote unit (RU) and the centralized unit (CU) whereby more or less base functionalities will be centralized depending on the split option. For example, a MAC-PHY split provides a substantial bandwidth reduction compared to traditional CPRI.

In an NGFI architecture implemented with a so-called ideal fronthaul, some functional split options will maintain most of the digital signal processing functions in the BBU. In this case, the fronthaul transport needs to satisfy the synchronization requirements of 5G RAN features such as Massive MIMO, Carrier Aggregation (CA), and Joint Processing (JT). The functional split depends mainly on the availability of an ideal and non-ideal transport network. In a non-ideal fronthaul transport case, the functional split needs to occur at a higher level in the LTE protocol stack, which reduces the level of centralization that can be achieved in the cRAN hub. In this case, the synchronization and bandwidth requirements can be relaxed at the expense of some of these 5G RAN features.

The following two technical solutions could be implemented in the future to help overcome these obstacles.

- White Rabbit (WR) technology—a combination of physical layer and PTP timing. White Rabbit introduces the technique of measuring and compensation for asymmetry to mitigate time and phase transfer error.
- Partial timing support compatible with the ITU standard G.8275.2 where the position of a GMC is moved close to the PTP slaves in the remote radio heads. This is an excellent alternative to full on-path support White Rabbit for those operators who are not willing or cannot upgrade their networks for White Rabbit physical layer support.

The following two illustrations highlight the White Rabbit full on-path support physical layer approach and the G.8275.2 partial on-path support approach.

Figure 7 • NGFI Timing and Sync—White Rabbit Full On-Path Support

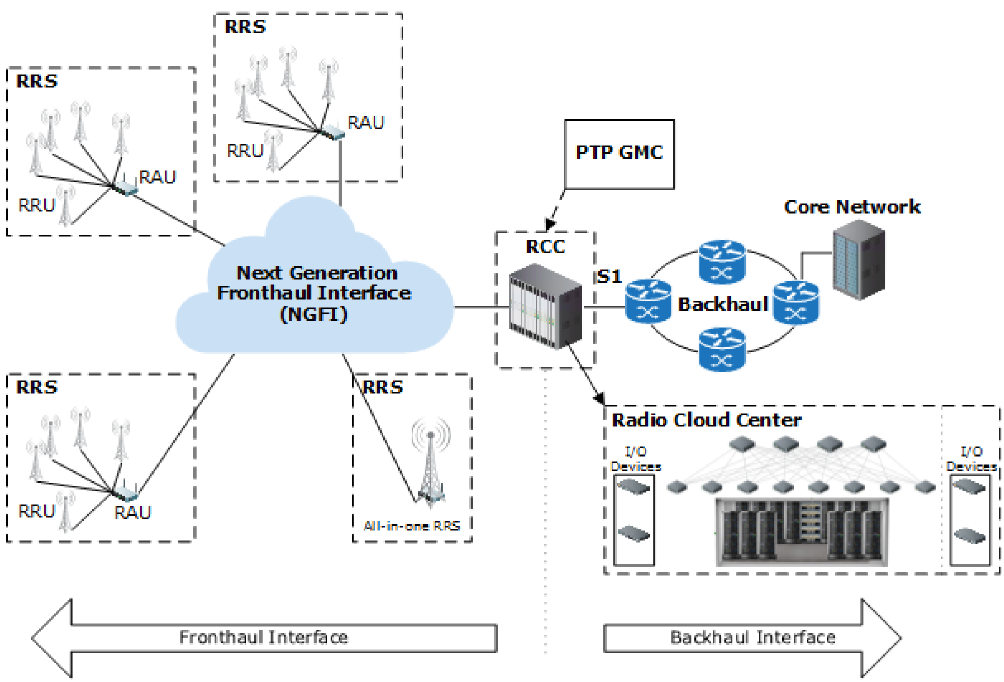
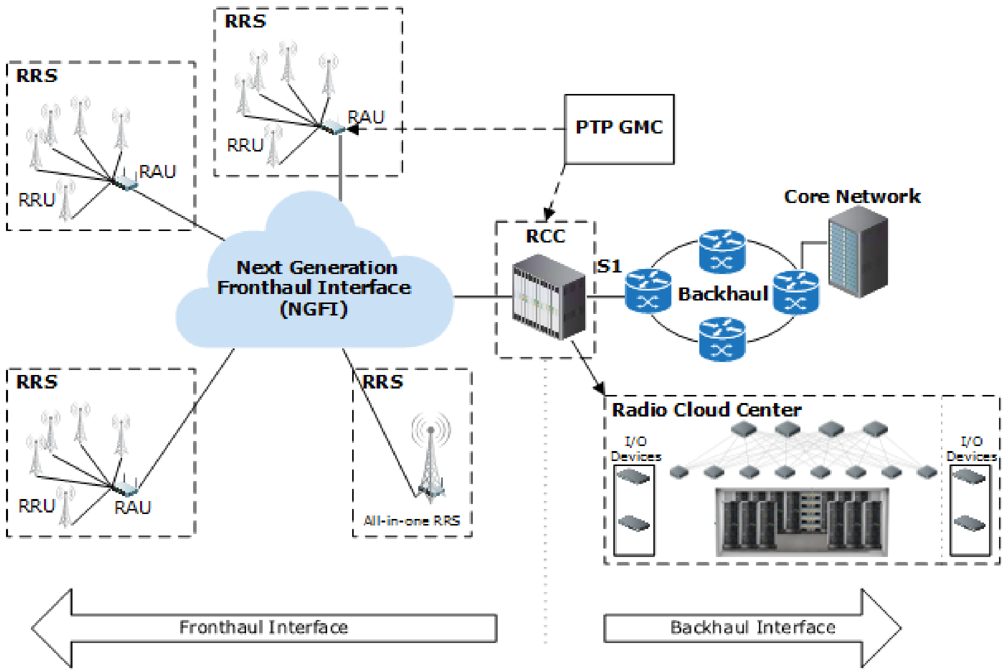


Figure 8 • NGFI Timing and Sync G.8275.2—Partial On-Path Support



Summary

Mobile architectures are evolving to support 5G densification in major metro markets. Mobile fronthaul and NGFI will be adopted and deployed. This will drive the evolution of CPRI, new standards and architectures for timing. Timing will be a critical part of the infrastructure and the deployment of GMCs in cRAN HUBS will be not only a good business investment but also a sound technical investment.

The attributes of a GMC, such as no single point of failure, holdover, PTP backup with asymmetry compensation, and the capability of repurposing this technology as CPRI evolves to OTN and Ethernet use cases, makes PTP and the deployment of GMCs the best and logical choice as the timing technology for cRAN and future vRAN mobile architectures.

Jim Olsen
Solutions Architect
Microsemi FTD
Jim.Olsen@Microsemi.com

Microsemi Corporate Headquarters
One Enterprise, Aliso Viejo,
CA 92656 USA
Within the USA: +1 (800) 713-4113
Outside the USA: +1 (949) 380-6100
Fax: +1 (949) 215-4996
Email: sales.support@microsemi.com
www.microsemi.com

900-00786-000