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Maximizing interworking and bandwidth efficiency in mobile transport networks

Benefits of Radio over Ethernet

White paper

Architectural changes in the radio access network (RAN) enabled by new functional splits between the baseband unit (BBU) and remote radio head (RRH) bring new possibilities to optimize and scale the network using Cloud-RAN (C-RAN). To help minimize transport costs, particularly in the fronthaul segment, 5G radios use the new Ethernet-based enhanced Common Public Radio Interface (eCPRI) protocol, which permits baseband signal transport over a packet fronthaul network. This enables operators to use statistical multiplexing of packet flows to make transport more efficient.

To take full advantage of packet fronthaul, the traffic streams coming from the large installed base of 4G CPRI-based radios and any new 5G CPRI radios must be packetized for transport over Ethernet networks. The IEEE 1914.3 Radio over Ethernet (RoE) standard addresses this need by specifying a transport protocol and encapsulation formats for transporting these time-sensitive radio streams over Ethernet. This white paper explores the capabilities and benefits of the different RoE modes and examines the benefits of gaining visibility into the underlying CPRI streams.

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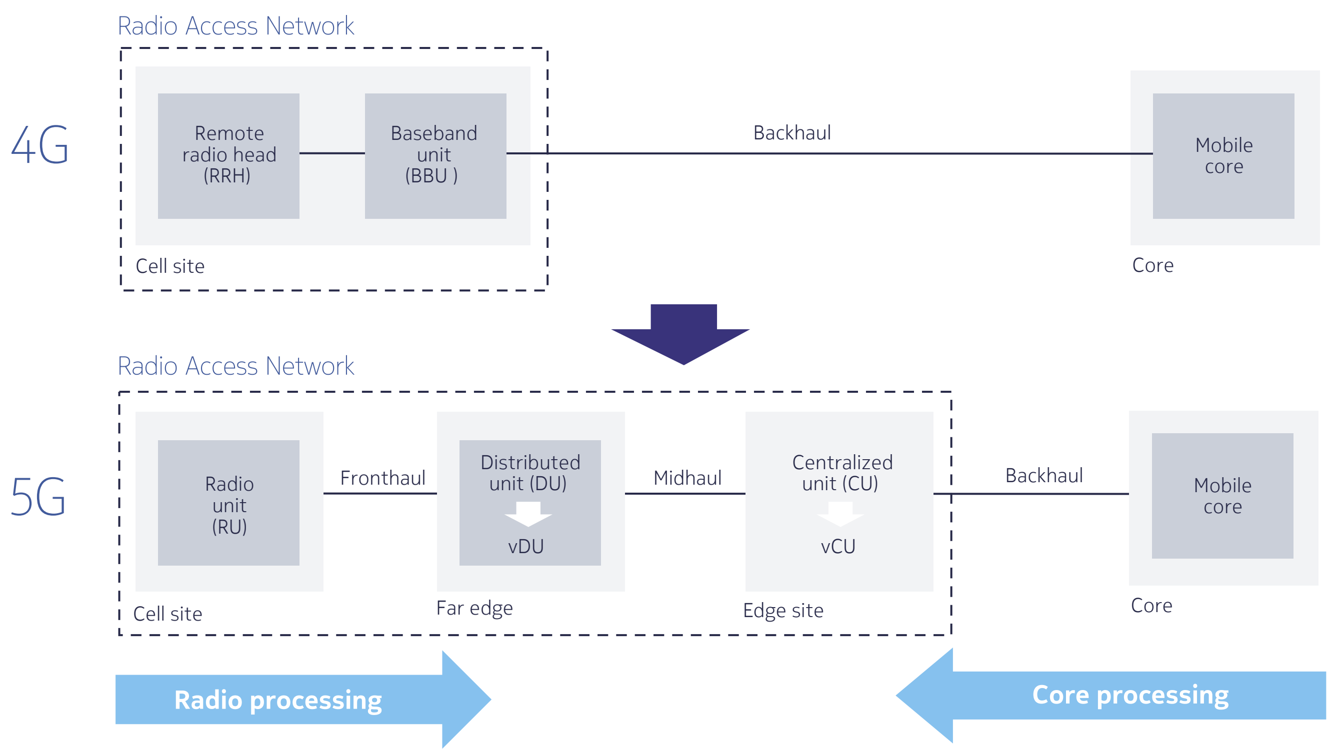
Background

5G brings flexibility into RAN architectures by disaggregating the RAN functions with the goal of improving performance. For the core part of the network, the trend is to move the core processing closer to the network edge to ensure low latency and better performance. This will also help offload some of the traffic from the central core network because part of the traffic remains local at the network edge. For the RAN part of the network architecture, the trend is to centralize the radio processing of the baseband with physical infrastructure serving as a BBU hotel or with virtualized RAN (vRAN) that decouples the hardware and software and permits flexible placement of the baseband functions. These approaches enable baseband pooling gains while simplifying cell sites.

With vRAN, it is possible to centralize virtualized central units (vCUs) higher and virtualized distributed units (vDUs) lower in the network hierarchy (Figure 1) to improve scalability and use commercial off-the-shelf (COTS) hardware to reduce costs. To ensure good radio performance, the fronthaul transport network must provide low-latency connectivity between the radios and any centralized baseband or vDUs located at the far edge hub site.

Figure 1. Disaggregation of RAN and core functions with processing moving to the network edge

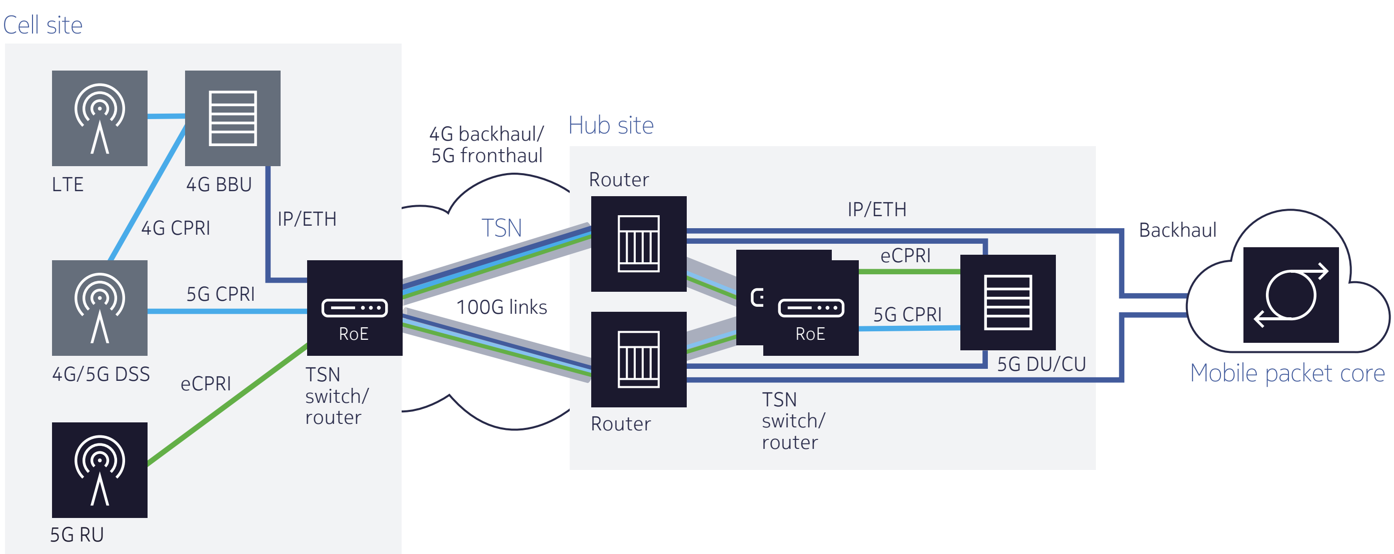


This fronthaul connectivity, which has traditionally used the CPRI protocol, is evolving to packet-based protocols that will reduce cost and improve flexibility. High-capacity 5G radios are primarily moving to new packet-based protocols such as eCPRI that better scale to support radios at higher frequency bands where larger numbers of antenna elements (e.g., massive MIMO) are used, and where the CPRI protocol does not scale well.

In some cases, established operators are looking to quickly add capacity at existing 4G sites using new multiband radios that support both 4G and 5G using dynamic spectrum sharing (DSS). These radios utilize the CPRI protocol to connect to the 4G baseband (BBU) at the cell site and the 5G baseband (DU/CU) at the hub site (Figure 2). To avoid costly transport overlays, a Time-Sensitive Networking (TSN) switch or router is used to combine all mobility traffic flows (IP/Eth backhaul, 5G CPRI fronthaul and eCPRI fronthaul) towards the hub site.

Since the 5G CPRI flow is a continuous stream of time-domain radio waveform samples that does not provide the possibility of gains from statistical multiplexing, it must first be mapped to Ethernet using RoE encapsulation for transport over a time-sensitive packet fronthaul network, adhering to strict latency and synchronization requirements. Any intermediate nodes, such as aggregation routers used to add switching scalability and redundancy, would support "pass through" of the RoE traffic streams. At the hub site, the RoE stream would be demapped back to CPRI for connection to the BBU.

Figure 2. Centralization of 5G baseband functions leading to hybrid 4G D-RAN/5G C-RAN



This architecture has the advantage of providing backwards compatibility with existing equipment. The CPRI-Ethernet "mappers" and "demappers" at the edges of the transport network would allow existing RAN equipment to transfer CPRI signals, thereby enabling operators to get more value from their existing investments. While not shown in the figure, 4G CPRI radios could connect to centralized 4G baseband using RoE in the same manner.

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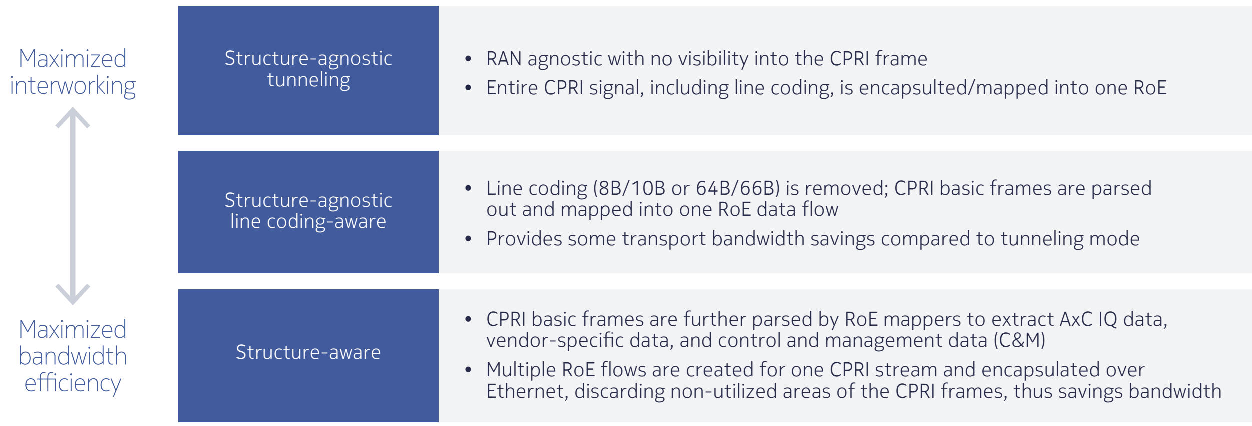
The IEEE 1914.3 working group has developed a new RoE standard that defines several methods for mapping CPRI streams (or streams from other protocols such as OBSAI) onto Ethernet frames [1]. Using this standardized approach, serial CPRI streams can be mapped onto Ethernet frames for transport over a packet fronthaul network and converted back to CPRI on the other end. This packetization of 4G CPRI flows allows them to coexist with 5G eCPRI, backhaul and other IP and business Ethernet access flows, all of which can share the same converged Ethernet transport network.

RoE modes and use cases

The IEEE 1914.3 working group has developed different RoE mapping modes that can maximize either multivendor interworking or bandwidth efficiency. It classifies these modes as either structure-agnostic mapping modes (including tunneling mode and line coding aware mode) and structure-aware mapping modes, as shown in Figure 3.

Figure 3. RoE mapping modes



The structure-agnostic tunneling mode performs as a simple Ethernet tunnel. Its primary benefit is that it is fully RAN vendor agnostic. This mode requires no visibility into the CPRI frame and does not interpret any special characters of the CPRI stream; it simply encapsulates the entire data stream. In this mode, all CPRI information, including the line coding, is encapsulated into RoE frames and transported transparently. Structure-agnostic tunneling mode is suitable for use cases that require a simple solution to connect RAN equipment for which CPRI structure details are unknown or unavailable. It offers a universal solution that allows operators to leverage packet transport and maximize multivendor interworking. However, this simplicity does not create bandwidth savings and comes with a header penalty because the entire CPRI data stream is being encapsulated.

In the structure-agnostic line coding-aware mode, the mapper understands the CPRI line coding (e.g., CPRI encoded with 8b/10b or 64b/66b) and removes it from the Ethernet flow. The data stream (except for the line coding) is encapsulated and passed as a binary stream. For commonly used CPRI rates up to CPRI-7 that use 8b/10b line coding, the bandwidth savings of line coding-aware mode compared to tunneling mode is approximately 20 percent. Line coding-aware mode is useful when the RAN equipment uses standard 8b/10 or 64b/66b line coding. The use of proprietary CPRI line coding data prevents the use and corresponding bandwidth savings of this mode.

Unlike the two structure-agnostic modes, the structure-aware mapping mode uses knowledge of the proprietary internal CPRI frame structure to remove unused CPRI frame information. It divides the content of the basic CPRI frame into separate packet flows and separates CPRI control words from the data payload. Unused bits that are part of the original CPRI frame are discarded before the CPRI stream is mapped into RoE packets, significantly increasing transport efficiency. The RoE mapper requires visibility into the internal proprietary CPRI frame structure, so applicability is limited to use cases where this structure is known.

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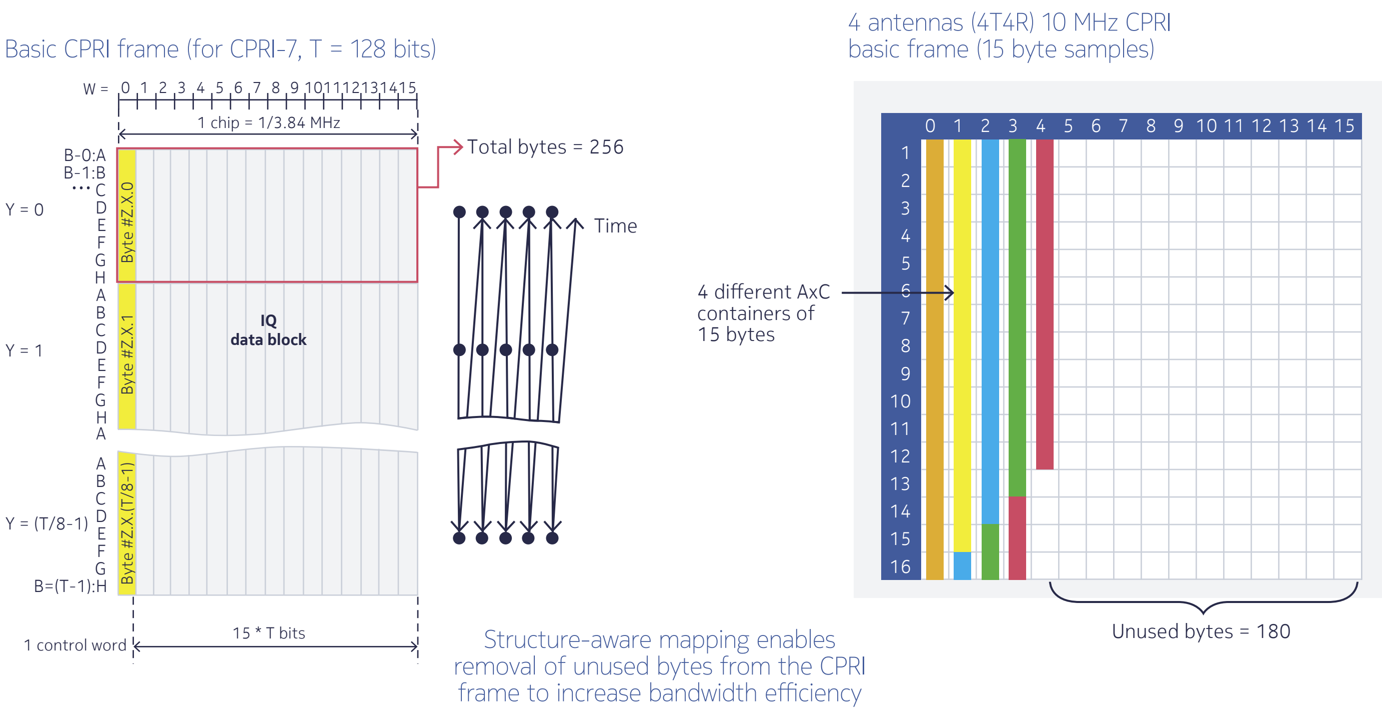
The actual bandwidth savings attained from using structure-aware mode depends on the specifics of the RAN configuration. Several parameters will impact the antenna carrier (AxC) occupancy level, including the CPRI rate, carrier spectral bandwidth (MHz), IQ sample size and the MIMO configuration, which corresponds to the number of AxCs. For example, a higher AxC occupancy level means a higher fill rate within the traffic stream and fewer empty containers that can be discarded. Figure 4 shows a basic CPRI frame for a 10MHz 4T4R CPRI-7 radio. The frame has a total of 256 bytes, which can be reduced to 76 bytes by removing the unused bytes. This creates a bandwidth savings of 70 percent. In addition, several other factors can impact the transport savings, including the RoE payload size, RoE header and Ethernet overhead ratio, although their impact would not be substantial.

Figure 4. RoE structure-aware mapping

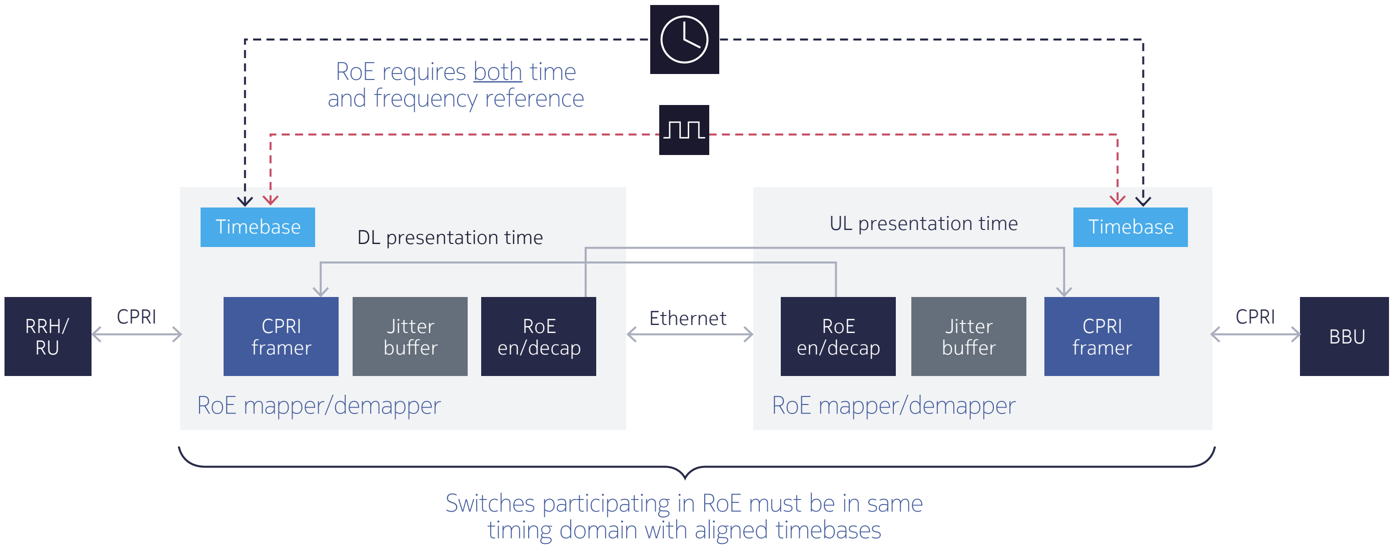


Importance of synchronization for RoE

RoE requires the use of a jitter buffer to absorb packet delay variation between RoE nodes. It also requires tight control of time and frequency synchronization. To ensure that the CPRI radio signal is presented at the exact time that the RAN expects the CPRI frames, both ends of the RoE link need a common time-of-day (ToD) reference. The RoE nodes that provide the end-to-end service must be in the same time domain and have aligned timebases, as shown in Figure 5.

The RoE nodes employ a differential timing method to distribute the common ToD reference using IEEE 1588v2 Precision Timing Protocol (PTP). This requires phase-alignment of the data transfer between RoE endpoints using the presentation time. The presentation time of the CPRI frame at the egress RoE node is propagated from the ingress RoE node to the egress RoE node. Based on the presentation time, the egress RoE node controls the CPRI frame timing so that the CPRI frame is conveyed at the exact time it is expected.

Figure 5. Synchronization in support of RoE

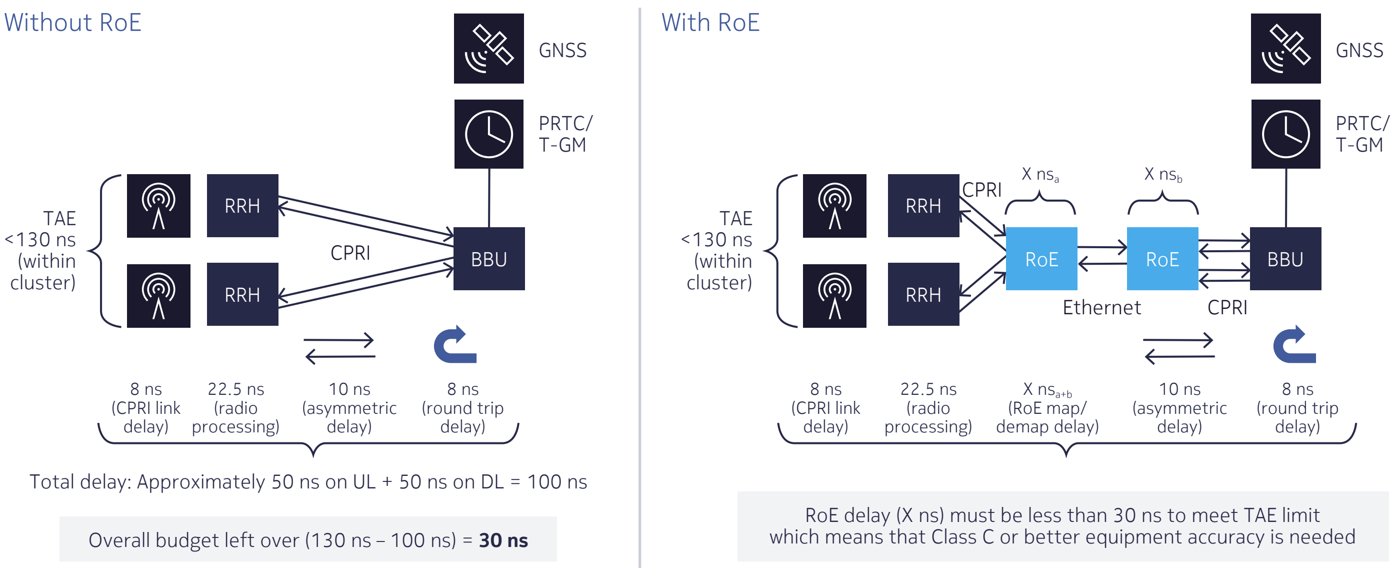


With RoE, the end application recovers the frequency from the CPRI bit rate. The RoE node maintains the integrity of the bit rate. RoE nodes need a high-quality oven-controlled crystal oscillator (OCXO) and telecom digital phase locked loop (DPLL) to provide a stable frequency so they can recover the CPRI bit rate. The end application needs frequency accuracy to meet the 3GPP requirement of 50 ppb at the radio air interface. To support this requirement, the transport network must be able to deliver 16 ppb (over the long term) or better, adding some internal budget and budget for holdover. As an example, ITU-T G.8261.1 (network limits for frequency sync over packet) explicitly refers to 16 ppb [2]. Additionally, having a stable frequency aids in accurate time and phase recovery and helps in bounding the phase noise, resulting in a smaller time error. The RoE node uses this recovered time in the presentation time, as explained above.

Another important consideration is the need to meet the overall time alignment error requirements to ensure proper RAN performance. To ensure that mobile devices properly receive and decode the signals from RUs with transmission diversity (e.g., MIMO, carrier aggregation), the signal frames must be aligned in time within a specified range. The requirements depend on the RAN configuration. For example, intra-band contiguous carrier aggregation requires ±130 ns time alignment between RUs within the same cluster, while intra-band non-contiguous and inter-band carrier aggregation require ±260 ns relative time alignment between involved RUs. High synchronization accuracy is essential because the introduction of RoE mapping/demapping inevitably introduces some timing error between the radios.

Figure 6 shows a time budget example for intra-band contiguous carrier aggregation. In this example, 100 ns of the 130 ns time error budget is consumed by the radio and baseband processing. This leaves only 30 ns for the endpoint RoE nodes, which implies that the sum of their map/demap delay (X ns a+b) must be 30 ns or lower. Thus, the RoE nodes must conform to a max|TE| of ITU-T G.8273.2 T-BC Class C or better.

Figure 6. Time budget example for intra-band contiguous carrier aggregation



Summary

Architectural changes in the RAN enabled by new functional splits between the BBU and RRH bring new possibilities to optimize and scale the network. In the RAN, the trend is to centralize the radio processing with a BBU hotel or with vRAN, with packet transport connectivity between the baseband and radios. To take advantage of packet transport efficiencies, the traffic streams that come from 4G/5G CPRI-based radios must be packetized.

By employing a mix of the standardized RoE mapping modes, operators can optimize their packet transport networks for maximum interoperability or bandwidth efficiency. These mappings allow operators to reduce cost by using existing CPRI radios and BBUs. They also allow 4G/5G CPRI flows to coexist with 5G eCPRI flows on the same packet transport network. Because of the strict latency and synchronization requirements of RoE mapping, operators need a transport network that consists of TSN switches and routers to provide the performance required to address the fronthaul, midhaul and backhaul traffic found in hybrid D-RAN/C-RAN environments. By optimizing their transport networks with RoE mapping, operators can improve the utilization of RAN resources (such as baseband processing) while taking advantage of statistical multiplexing gains to lower the aggregate bit rate requirements of some links and paving the way towards supporting vRAN architectures.

Learn more

Listen to our podcast to learn more about the importance of Radio over Ethernet for 5G.

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Glossary

3GPP	3rd Generation Partnership Project
AxC	antenna carrier
BBU	baseband unit
C&M	control and management
COTS	commercial off-the-shelf
CPRI	Common Public Radio Interface
C-RAN	Cloud-RAN
CU	centralized unit
DL	downlink
DPLL	digital phase locked loop
DSS	dynamic spectrum sharing
DU	distributed unit
eCPRI	enhanced CPRI
Gbps	gigabits per second
GNSS	Global Navigation Satellite System
IEEE	Institute of Electrical and Electronics Engineers
IP/ETH	Internet Protocol/Ethernet
IQ	in-phase quadrature
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
Max |TE|	maximum time error
MHz	megahertz
mMIMO	massive multiple-input, multiple-output
ns	nanosecond
OBSAI	Open Base Station Architecture Initiative
OCXO	oven-controlled crystal oscillator
ppb	parts per billion
PRTC	primary reference timing clock
PTP	Precision Time Protocol
RAN	radio access network
RRH	remote radio head
RU	radio unit

TAE	time alignment error
T-BC	telecom boundary clock
T-GM	telecom grand master
ToD	time of day
TSN	Time Sensitive Networking
UL	uplink
vCU	virtualized centralized unit
vDU	virtualized distributed unit
vRAN	virtualized radio access network

References

1. IEEE Std 1914.3™-2018, IEEE Standard for Radio over Ethernet Encapsulations and Mappings
2. ITU-T G.8261.1/Y.1361.1 (02/12), Packet delay variation network limits applicable to packet-based methods (Frequency synchronization)

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