Understanding the CPRI Specification and Its Successor, eCPRI

SIGNAL CRAFT TECHNOLOGIES

Introduction

Every generation of mobile network brings about new technology and infrastructure improvements to support faster data rates, greater bandwidth, and improved efficiency and coverage. To keep up with these advancements, base station architectures have steadily evolved over time. The introduction of fourth generation cellular (4G) required major changes in the traditional analog radio architecture, such as the migration of all analog circuitry to the remote radio unit (RRU). This migration included the elimination of the coaxial connection between the baseband unit (BBU) and RRU, a common source of signal degradation due to insertion loss, reflections, and other imperfections encountered along the signal path. Now the BBU and RRU can be separated by up to 20 km of high-performance, high-throughput fiber-optic cabling. The Common Public Radio Interface (CPRI) is the specification that defines the communication protocol running over the dedicated fiber link.

This whitepaper provides a high-level overview of CPRI as a practical resource for RAN engineers. The latter portion of the article also describes the eCPRI specification, the next evolution of CPRI for 5G networks.

Because CPRI was developed as an open specification by multiple industry parties, it supports a multitude of deployment, equipment, and vendor specific configurations.

Overview of CPRI Specification

CPRI is a high-speed serial communication protocol for transferring digitized radio data and control information between the BBU (also called the Radio Equipment Control or REC) and RRU (also called the Radio Equipment or RE). In the Downlink (DL) path, the REC is responsible for signal conditioning and conversion of data into in-phase and quadrature (IQ) data, prior to sending it to the RE via the CPRI link. The RE converts the digitized IQ data back to analog RF signals and transmits it over the air via the antenna. Conversely, a similar process occurs in the opposite, or Uplink (UL), path.

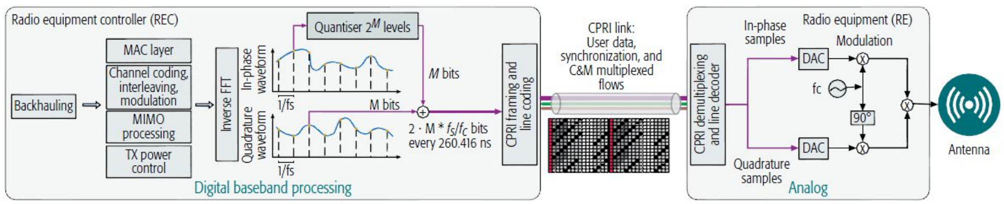


Figure 1. Functionalities of the REC and RE for the Downlink path (source: IEEE)

Key Features of CPRI

Because CPRI was developed as an open specification by multiple industry parties – including Ericsson, Huawei, NEC, and Nokia – one of its strengths (and sometimes complications) is that the “standard” supports a multitude of deployment, equipment, and vendor specific configurations. The protocol lays out a basic architecture for communication between the REC and RE, while still allowing flexibility for manufacturers to customize their equipment and for carriers to customize their own infrastructure to their specific operating needs.

Below are some of the main requirements and functionalities that the CPRI specification defines:

- The interface must be able to support multiple radio standards, including 3GPP UTRA FDD, WiMAX, 3GPP E-UTRA, and 3GPP GSM/EDGE.
- A wide range of channel bandwidths are supported. For example, the transmission bandwidth of CDMA is 1.25 MHz, while the transmission bandwidth of LTE can be as much as 20 MHz.
- CPRI allows REs to support one or multiple antennae. For example, a typical topology may use 1 to 4 carriers x 2 antennas x 3 sectors per RE for a total of 6 IQ streams.
- While the most basic configuration consists of a point-to-point connection between one REC and one RE, the specification outlines numerous network topologies including star, chain, tree, ring, and multi-hop connections.

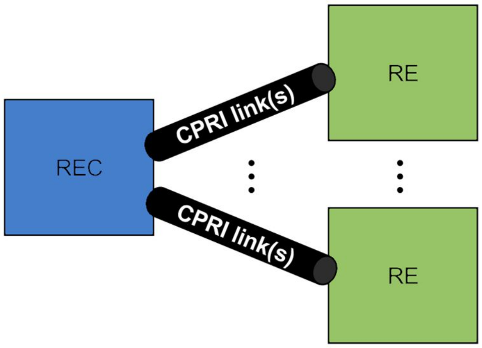


Figure 2. Star topology using CPRI links (source: CPRI.info)

CPRI Protocol Stack

The CPRI specification defines the physical (layer 1) and data link (layer 2) requirements. Once the physical link is established, different information flows have access to layer 2 via service access points (SAPs). The three types of information flows are:

- User plane data that carries IQ data samples
- Control and management (C&M) data used to monitor and control the REs
- Synchronization data used for frame and time alignment

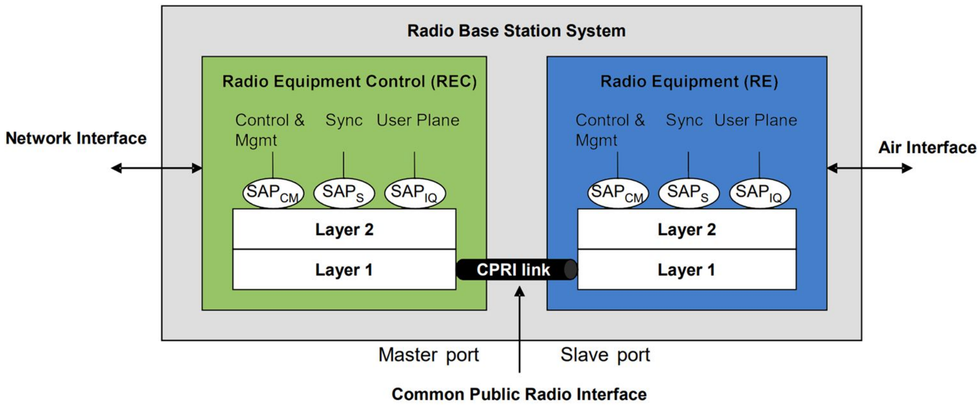


Figure 3. CPRI system architecture and interface definition (source: CPRI.info)

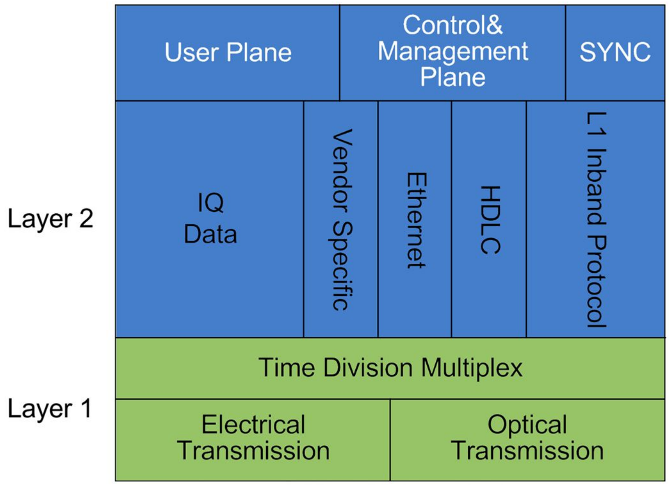


Figure 4. CPRI protocol stack (source: CPRI.info)

CPRI Frame Structure

As a digital serial communication protocol, CPRI packages and transports IQ data using the following frame hierarchy:

- 16 words per basic frame (one for control and fifteen for IQ data)
- 256 basic frames per hyperframe
- 150 hyperframes per CPRI 10ms frame (or UMTS radio frame)

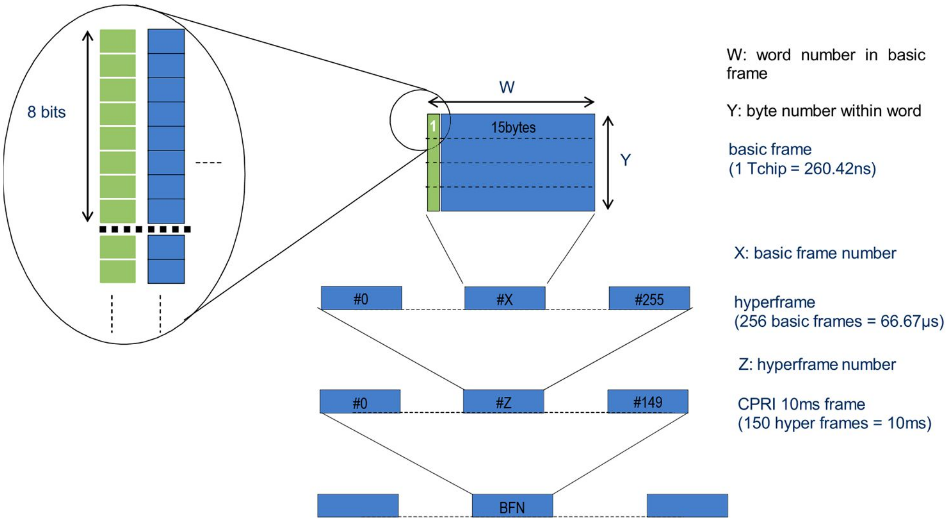


Figure 5. CPRI frame structure (source: CPRI.info)

Figure 6 shows a generic frame structure that expands the word length based on the specified CPRI line rate. B is the bit index (0 to 7), W is the word index (0 to 15), Y is the byte index within the word, and T refers to the word length in bits. In the control word, Z is the hyperframe number (0 to 149) and X is the basic frame number (0 to 255).

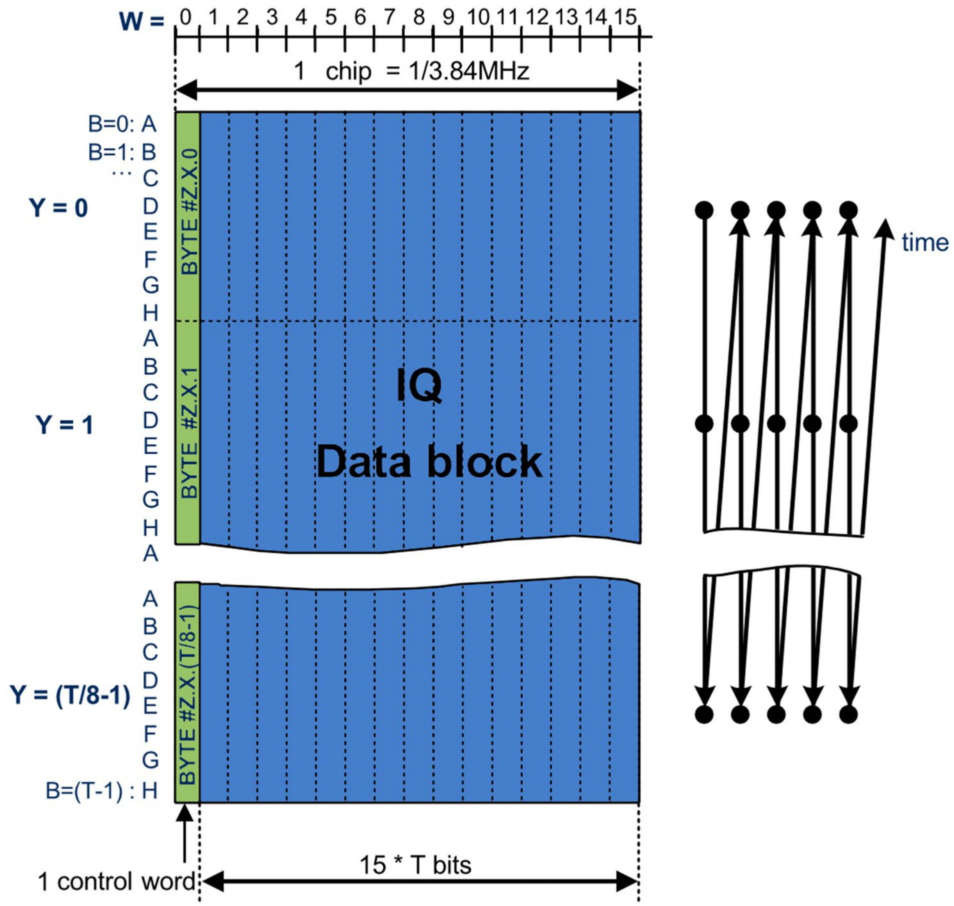


Figure 6. Generic basic frame structure (source: CPRI.info)

In a basic frame, the size or length of the word increases with higher line bit rates. As of CPRI specification V7.0, the protocol supports ten line rate options, all of which are multiples of the basic frame rate (or basic UMTS chip rate) of 3.84 Mbit/s for maximum cost efficiency.

Line Rate Option #	Line Rate (Mbit/s)	Word Size (bytes)
1	614.4	1
2	1228.8	2
3	2457.6	4
4	3072.0	5
5	4915.2	8
6	6144.0	10
7	9830.4	16
8	10137.6	20
9	12165.12	24
10	24330.24	48

Table 1. CPRI Line Rates

CPRI supports two types of C&M channels – a slow link based on high-level data link control (HDLC) and a fast link based on Ethernet.

C&M Plane and Control Words

With regards to the control word, a hyperframe contains 256 control words, one for each basic frame. This distribution of control words across a hyperframe provide all the ongoing control, management, synchronization, vendor-specific, and other layer 2 information mentioned in Figure 4.

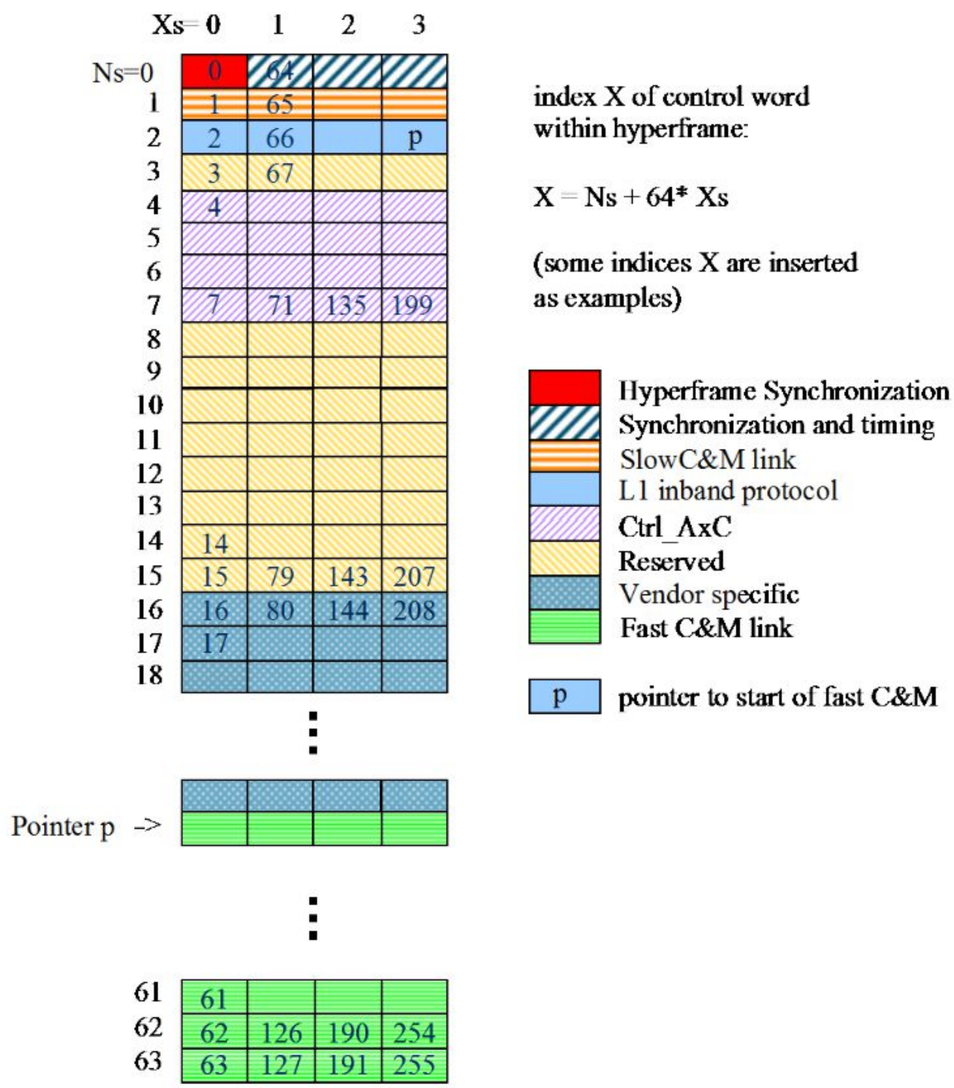


Figure 7. Organization of control words in a hyperframe (source: CPRI.info)

CPRI supports two types of C&M channels – a slow link based on high-level data link control (HDLC) and a fast link based on Ethernet. Although use of the C&M channel is optional, the CPRI specification strongly recommends that at least one of the two C&M channel types be incorporated into the equipment. Depending on how many control words are used for the fast C&M link, 16 to 192 control words will be left in each hyperframe for vendor-specific data use.

CPRI defines three mapping methods for organizing AxC containers into the IQ data block: IQ sample based, WiMAX symbol based, and backward compatible.

User Plane and IQ Data Mapping

The second data flow type defined in CPRI is the User Plane. The analog data is sampled and digitized into I and Q components. These I and Q samples for each sector or antenna are chronologically and consecutively interleaved into individual antenna-carrier (AxC) containers. Data is sequenced from least significant bit (LSB) to most significant bit (MSB).

The size of an AxC container is determined by the sample rate and sample size (anywhere from 8 to 20 bits for downlink and 4 to 40 bits for uplink). For example, if the sample size is set at 15 bits, then the AxC consists of 15 bits of I-data and 15 bits of Q-data for a total of 30 bits. With line rate option 3 (see Table 1), a basic frame contains 4 words for control data and 60 words for IQ data (or 60 words x 8 bits/word = 480 bits of IQ data). This results in 480 bits/30 bits per AxC = 16 AxCs per basic frame for line option 3.

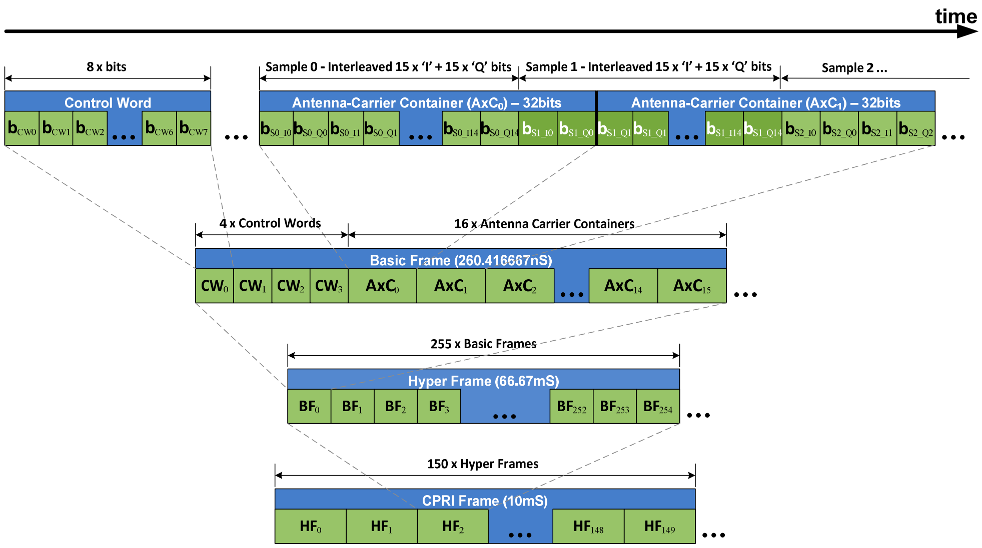


Figure 8. AxC containers for line rate option 3

CPRI defines three mapping methods for organizing AxC containers into the IQ data block: (1) IQ sample based, (2) WiMAX symbol based, and (3) backward compatible. Mapping is further complicated with the need to support multiple wireless protocols, as well as multiple vendor-specific configurations and data.

As an example, Figure 9 shows mapping method 1 applied to the LTE standard. One AxC container block carries S number of IQ sample bits per LTE AxC, mapped in chronological order. The AxC container may also start with N_{ST} number of stuffing bits, which are vendor-specific bits used to align sample frequencies that are not an integer multiple of 3.84 MHz CPRI basic frame frequency.

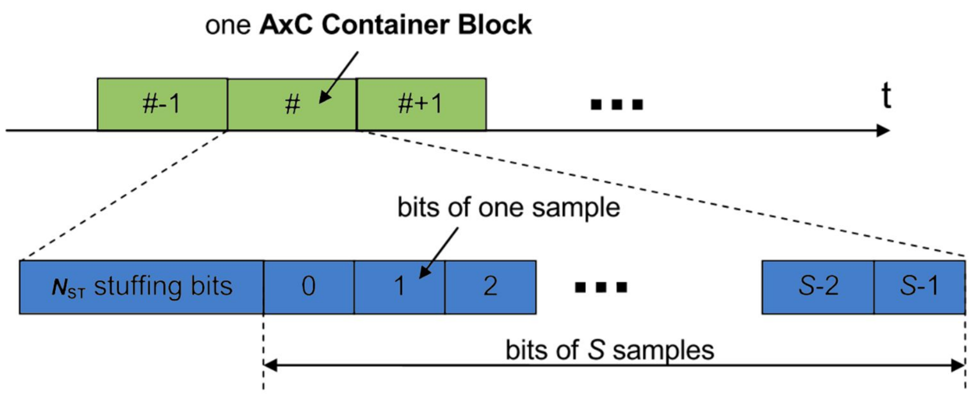


Figure 9. Mapping method 1 for an AxC container block (source: CPRI.info)

Because the vendor-specific data can include a myriad of configuration and control parameters, these settings may differ from site to site, even on the same vendor's equipment.

Because the vendor-specific data can include a myriad of configuration and control parameters, these settings may differ from site to site, even on the same vendor's equipment. This means the mapping of IQ data for each antenna can be arbitrarily allocated into antenna containers. These factors can significantly complicate test equipment setup for RAN engineers needing to tap into the CPRI link to examine UL spectrum. This may lead to extra time and frustration for the RAN engineer to try to determine how to properly configure the test equipment to align with vendor-specific data.

Synchronization Plane

The synchronization between AxC container blocks and CPRI framing also differs depending on the wireless network protocol. For GSM, the REC notifies the RE about timing relation between the GSM frame and CPRI 10ms frame (which may differ for uplink versus downlink). For every 60 ms, 13 GSM frames are mapped onto 6 CPRI frames. The first CPRI basic frame of the first GSM frame (of every 13 x GSM frame) is always aligned with the first CPRI basic frame of an AxC container block.

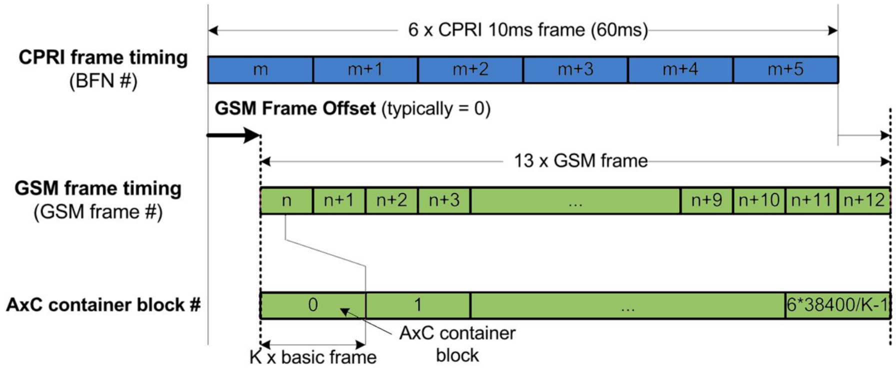


Figure 10. Timing relation between GSM frames and CRPI 10ms frames (source: CPRI.info)

With 5G networks on the horizon, the density of REs will significantly increase to meet the need for faster data rates, lower latency, and widespread coverage.

eCPRI: The Next Evolution of CPRI

With 5G networks on the horizon, the density of REs will significantly increase to meet the need for faster data rates, lower latency, and widespread coverage. Although the RE needs to reside near or at the antennae, the REC can be consolidated into common areas to reduce deployment and maintenance costs. Running dedicated optical fiber links to each RE is neither practical nor economical. Therefore, eCPRI seeks to leverage existing network infrastructure, such as Ethernet, for the fronthaul transport network. This new eCPRI fronthaul would allow for a truly distributed cloud-based radio access network (C-RAN) architecture to be realized where, for instance, a site contains five to six centralized RECs that each talk to dozens of remote REs over Ethernet.

Key Features of eCPRI

eCPRI is a new protocol with the same level of interoperability as CPRI, but it now specifies a packet-based fronthaul transport network interface for transferring user plane information (or IQ data) between the eREC and eRE. The specification does not limit the fronthaul to Ethernet-switched or IP-routed technologies, but their usage is highly encouraged because of their mainstream adoption and availability. Compare Figure 11 to Figure 3 and note the functional similarities between CPRI and eCPRI.

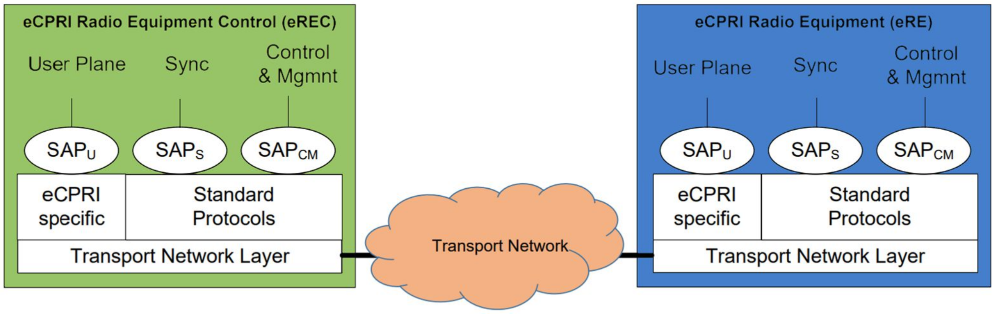


Figure 11. eCPRI system architecture and interface definition (source: CPRI.info)

The eCPRI specification does not define the communication protocols for C&M and synchronization information flows, but existing protocols and standards (such as TCP, UDP, and PTP) are proposed as possible options.

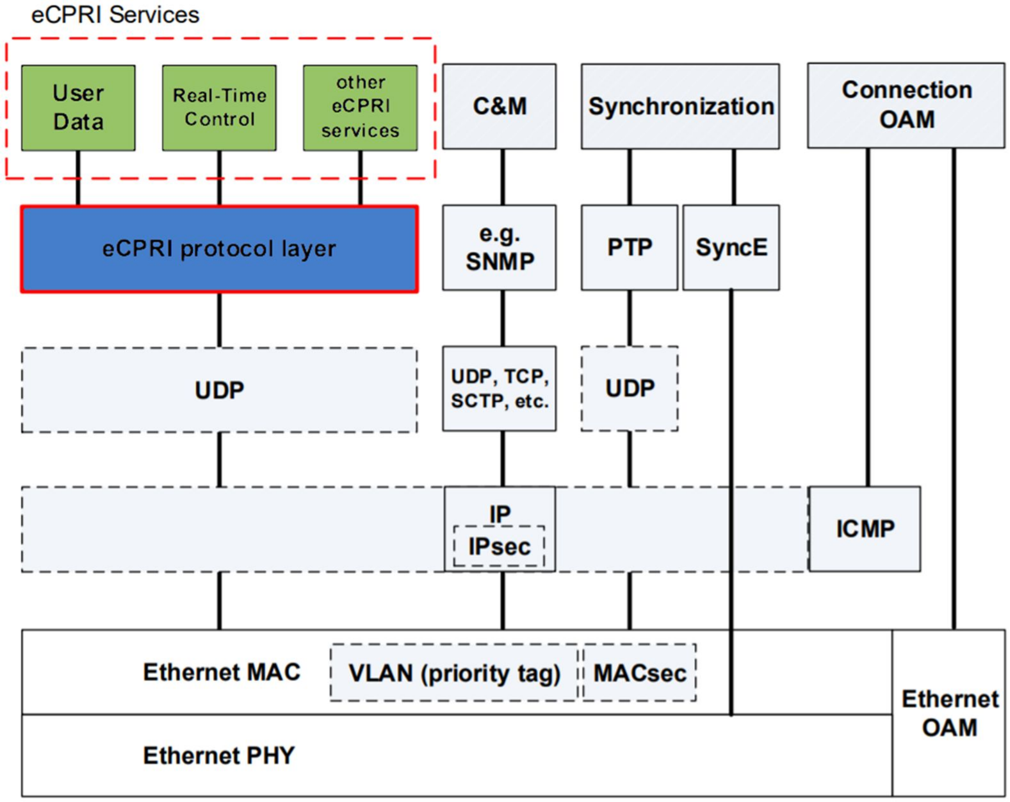


Figure 12. eCPRI protocol stack over IP / Ethernet (source: CPRI.info)

> eCPRI also aims to reduce the required bandwidth by tenfold and allow the required bandwidth to scale flexibly with the user plane traffic for greater utilization efficiency.

Another noteworthy change includes a functional split inside the PHY layer between the baseband and radio that allows for the introduction of new radio processing algorithms and other software updates without requiring changes in the radio equipment. eCPRI also aims to reduce the required bandwidth by tenfold and allow the required bandwidth to scale flexibly with the user plane traffic for greater utilization efficiency.

Networking for CPRI versus eCPRI

One of the main differences between CPRI and eCPRI is that CPRI requires a dedicated fiber optic link between the REC and RE and it supports both point-to-point (one REC to one RE) and point-to-multi-point (one REC to multiple REs) logical connections with corresponding master/slave ports. The networking layer functions are not defined by CPRI, and therefore supported topologies, redundancy, quality of service (QoS), and security depend on the REC and RE functions.

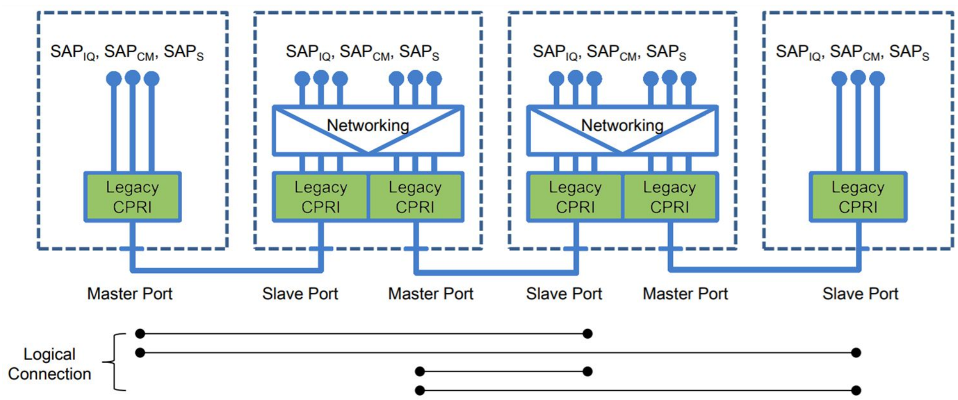
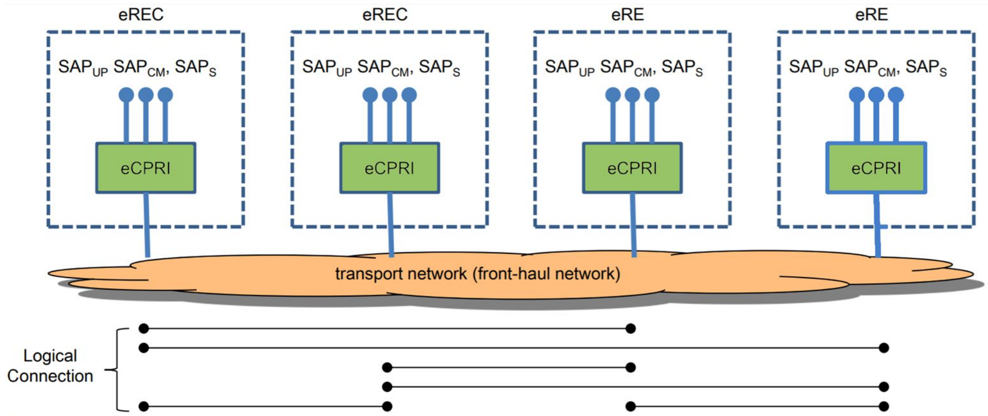


Figure 13. Networking by CPRI (source: CPRI.info)

With eCPRI, information between the eREC and eRE can be packetized over Ethernet and sent over the "cloud."

With eCPRI, information between the eREC and eRE can be packetized over Ethernet and sent over the "cloud," allowing for much greater network flexibility. The eCRPI layer lies above the transport networking layer and does not use master/slave port classifications at the physical level. In addition to point-to-point and point-to-multi-point setups, eCPRI also supports multi-point-to-multi-point logical connections (such as eRECs to eREs, eRECs to eRECs, and eREs to eREs). eCPRI nodes must implement proper transport network layer protocols to support redundancy, QoS, security, and other functions as needed.



4. Networking by eCRPI (source: CPRI.info)

As of June 2018, the CPRI organization is working on the updated eCPRI 2.0 specification with enhanced support for 5G technology. Plus, IEEE is currently drafting the new IEEE1914.3 Standard for Radio over Ethernet (RoE) that supports CPRI and defines how CPRI packets (specifically IQ data) will be encapsulated into Ethernet packets. Mainstream adoption is predicted to launch in two to five years, most likely starting in larger cities.

CPRI Analysis for RAN Engineers

Figure 15. SCT SIQMA SC2820 CPRI analyzer

Regardless of the protocol enhancements, ultimately RAN engineers are most concerned about the ability to easily pull out the IQ samples from the CPRI link and convert them into spectral data in the frequency domain for analysis. At SCT, we offer the SIQMA SC2820 as the highest performing, lowest cost CPRI analyzer on the market. Unlike other CPRI instruments, SIQMA not only captures every frame for 100% interference detection, but it also offers simultaneous antenna support and remote access for ease of use.

Common applications include interference hunting, passive intermodulation (PIM) detection, distributed antenna system (DAS) optimization, and fiber to the antenna (FTTA) troubleshooting. As eCPRI and 5G networks are implemented, SignalCraft is committed to updating the SIQMA product family to address all future protocol improvements.

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