An Overview of the CPRI Specification and Its Application to C-RAN-Based LTE Scenarios

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ABSTRACT

The CPRI specification has been introduced to enable the communication between radio equipment and radio equipment controllers, and is of particular interest for mobile operators willing to deploy their networks following the novel cloud radio access network approach. In such a case, CPRI provides an interface for the interconnection of remote radio heads with a baseband unit by means of the so-called fronthaul network. This article presents the CPRI specification, its concept, design, and interfaces, provides a use case for fronthaul dimensioning in a realistic LTE scenario, and proposes some interesting open research challenges in the next-generation 5G mobile network.

INTRODUCTION AND MOTIVATION

Mobile network operators (MNOs) have realized that the cloud radio access network (C-RAN) approach can provide a significant advantage with respect to their competitors in a market scenario where the trend in revenue per user is almost flat or decreasing. C-RAN has been recently introduced and further shown that significant operational expenditure (OPEX) and capital expenditure (CAPEX) reductions can be achieved with respect to traditional equipment deployments. A recent trial from China Mobile has shown 53 and 30 percent savings in OPEX and CAPEX, respectively [1].

The C-RAN approach advocates for the separation of the radio elements of the base station (called remote radio heads, RRHs) from the elements processing the baseband signal (called baseband units, BBUs), which are centralized in a single location or even virtualized into the cloud. This approach benefits from simpler radio equipment at the network edge, easier operation, and cheaper maintenance, while the main RAN intelligence (BBUs) is centralized in the operator-controlled premises. The challenge of C-RAN deployments is that such a functional split requires these two elements to be connected through a high-speed, low-latency, and accurately synchronized network, the so-called fronthaul. Such critical requirements are currently met with fiber optics [2, 3].

The C-RAN approach has some some clear benefits with respect to traditional integrated base stations (BSs). First, the cost of deploying RRHs decreases considerably since the installation footprint is much smaller. RRHs do not need any refrigeration or costly on-site construction, thus shortening the time for deployment compared to traditional integrated BSs. On the other hand, BBUs can be aggregated and further virtualized in BBU pools. In this way, BBUs can be shared and turned off when necessary, reducing the cost of maintaining a network with low loads. Finally, another benefit of C-RAN is that it enables the use of cooperative radio techniques, cooperative multipoint (CoMP), allowing reduction of the interference between different radio transmissions and improving its performance. This further enables denser RRH deployments than traditional ones since interference among BSs can be better mitigated [4].

A number of radio equipment manufacturers have defined two main specifications for the transport of fronthaul traffic: the Common Public Radio Interface (CPRI) [5] and the Open Base Station Architecture Initiative (OBSAI). Both solutions are based on the implementation of the digital radio over fiber (D-RoF) concept, whereby the radio signal is sampled and quantized, and, after encoding, transmitted toward the BBU pool. These two specifications differ in the way that information is transmitted. CPRI is a serial line interface transmitting constant bit rate (CBR) data over a dedicated channel, while OBSAI uses a packet-based interface. The mapping methods of CPRI are more efficient than OBSAI [6], and most global vendors have chosen CPRI for their products.

The aim of this article is to present the CPRI specification, its concept, design, and interfaces, and further provide a guideline for fronthaul dimensioning in realistic Long Term Evolution (LTE) scenarios. We also provide some interesting open research challenges and current initiatives to bring the C-RAN concept to the fifth-generation (5G) mobile network. Accordingly, the following section briefly reviews the LTE physical layer (PHY) specifications required to understand the design of CPRI. We then introduce the top-level fronthaul network requirements demanded by CPRI and its main features, including the user plane data, control and management, and synchronization information multiplexing. After that we provide an application example of

CPRI in a realistic LTE scenario. Finally, we conclude this work providing a number of open research issues and challenges regarding CPRI and the fronthaul.

LTE PHYSICAL MEDIA

This section presents the main features of the LTE PHY; in particular, LTE frequency-division duplex (LTE-FDD) is considered for brevity.

Concerning the downlink (DL), LTE uses orthogonal frequency-division multiple access (OFDMA), while in the uplink (UL) LTE uses single-carrier frequency-division multiple access (SC-FDMA). In both techniques data is encoded on multiple narrowband subcarriers, minimizing the negative effects of multi-path fading, distributing the interference effect across different users.

LTE allows spectrum flexibility where the channel bandwidth can be configured from 1.25 to 20 MHz. As an example, the DL with a 20 MHz channel and a 4×4 multiple-input multiple-output (MIMO) configuration can provide up to 300 Mb/s of user plane data. The UL peak data rate is 75 Mb/s.

LTE defines a generic frame structure that applies to both DL and UL for FDD operation. Each LTE frame has a duration of 10 ms, and is subdivided into 10 equal-size subframes of 1 ms; each subframe comprises two slot periods of 0.5 ms duration. Depending on the cyclic prefix (CP) duration, each slot carries a number of orthogonal frequency-division multiplexing (OFDM) symbols (7 for the short CP or 6 for the long CP) with $T_{symbol} = 66.67$ μs.

In the frequency domain, groups of N_{sc} = 12 adjacent subcarriers (15 kHz/subcarrier) are grouped together on a slot-by-slot basis to form so-called physical resource blocks (PRBs), which are the smallest bandwidth unit (180 kHz) assigned by the BS scheduler (Fig. 1). Thus, different transmission bandwidths use various PRBs per time slot, ranging from $N_{PRB} = 6$ to 100, as shown in Table 1.

Thus, each time slot carries a number of bits depending on the number of symbols per time slot (either 6 or 7), the modulation chosen, and the transmission bandwidth B_{tx}. For example, for B_{tx} = 2.5 MHz (144 subcarriers) with 64-quadrature amplitude modulation (QAM) (6 b/symbol) and short CP (N_{CP} = 7 OFDM symbols per time slot), the number of bits carried in a time slot of 0.5 ms duration is 6048 bits (144 subcarriers × 7 OFDM symbols × 6 b/symbol), and the resulting data rate is approximately 12 Mb/s. The effective data rate is actually less than this value since some resource elements of the PRB are reserved for control and signaling. It is also worth noting that there is one resource grid for each transmitting antenna; in other words, in a 2 × 2 MIMO configuration the value above doubles (24 Mb/s).

In order to recover all of the data transmitted, the receiver must take N_{FFT} samples per OFDM symbol (T_{symbol}) as specified in Table 1. In the example above, the receiver must take N_{FFT} = 256 samples per OFDM symbol (66.67 s) in order to recover the data transmitted in B_{tx} = 2.5 MHz. In this case, the sampling frequency is f_s = 3.84 MHz ($1.536 \cdot B_{tx}$, as shown in the table), and the sampling period $T_s = 1/f_s = 260.41416$ ns.
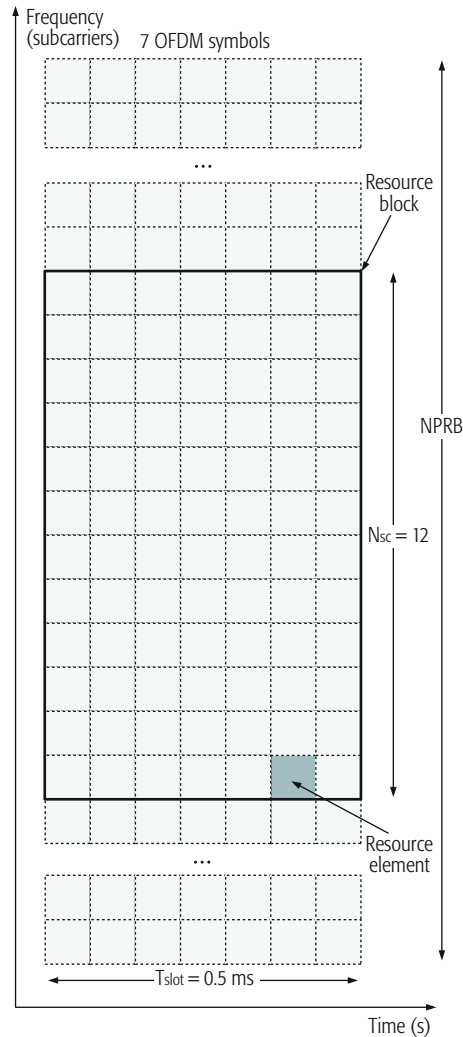

Figure 1. Downlink resource grid defined in LTE.

It is worth highlighting the importance of the f_s = 3.84 MHz sampling reference value of LTE FDD, since the timing and synchronization design of CPRI revolves around this number. Essentially, f_c = 3.84 MHz defines the main clock for CPRI framing, which is then oversampled to obtain the timing references for the other LTE channel bandwidths.[1] In addition, one CPRI basic frame is generated every $1/f_c$ = 260.416 ns to carry the sampled digitized OFDM symbol, thus completely aligned with the LTE time reference.

OVERVIEW OF CPRI
CONCEPT AND REQUIREMENTS

According to the CPRI specification v6.1 [5], *"the Common Public Radio Interface (CPRI) is an industry cooperation aimed at defining a publicly available specification for the key internal interface of radio base stations between the Radio Equipment Control (REC) and the Radio Equipment (RE)."* In other words, the CPRI specification provides the physical (L1) and data link layer (L2) details for the transport of digitized radio information between REC and RE.

Figure 2 shows the functional split between REC and RE as defined in the CPRI specification

Concerning downlink, LTE uses OFDMA, while in the uplink LTE uses SC-FDMA. In both techniques data is encoded on multiple narrowband subcarriers, minimizing the negative effects of multi-path fading, distributing the interference effect across different users.

[1] The value of this clock is inherited from the single clock used in multi-mode WCDMA user equipments.

Tx BW (Btx)	1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Number of PRB (N_{PRB})	6	12	25	50	75	100
FFT size (N_{FFT})	128	256	512	1024	1536	2048
Sampling frequency	1.92 MHz	3.84 MHz	7.68 MHz	15.36 MHz	23.04 MHz	30.72 MHz
($f_s = 15\text{KHz} \times N_{FFT}$)	(1/2 × 3.84 MHz)		(2 × 3.84 MHz)	(4 × 3.84 MHz)	(6 × 3.84 MHz)	(8 × 3.84 MHz)
Subcarriers/PRB (N_{sc})	12					
OFDM symbols (N_{CP})	7/6 (Short/Long CP)					
Modulation	QPSK, 16-QAM, 64-QAM					
MIMO configurations	4 × 2, 2 × 2, 1 × 2, 1 × 1					
I/Q data rate (Gb/s) per AxC	0.0576	0.1152	0.2304	0.4608	0.6912	0.9216

Table 1. Downlink OFDM modulation parameters and CPRI bandwidth required for the case of M = 15 b/sample.

(DL). As shown in the figure, all the operations above the PHY and most of those of the PHY are performed by the REC, which generates the radio signal, samples it, and sends the resulting data to the RE. The RE basically reconstructs the waveform and transmits it over the air. The uplink case is similar, although the sampling of the radio signal must be performed in the RE. The main benefit of this split is that almost no digital processing functions are required at the RRHs, making them very small and cheap. In addition, the centralization of all the signal processing functions in the BBU simplifies the adoption of cooperative techniques such as CoMP, which require advanced processing of the radio signal of several RRHs simultaneously. Further discussion on alternative functional splits can be found in [7].

Some of the main design features and requirements of CPRI are listed below:

• CPRI supports a wide variety of radio standards: Third Generation Partnership Project (3GPP) Universal Terrestrial Radio Access (UTRA) FDD, WiMAX, 3GPP Evolved UTRA (E-UTRA, LTE), and 3GPP GSM/EDGE. This article only focuses on the use of CPRI for the transport of the E-UTRA interface.

• Although in most practical configurations CPRI will be configured in a point-to-point fashion, the specification also allows different topology configurations: star, chain, tree, ring, and multihop options to carry CPRI data over multiple hops. For example, CPRI natively supports the multiplexing of two CPRI-1 (614.4 Mb/s) into a single CPRI-2 (1228.8 Mb/s) frame through daisy chaining of the REs.

• CPRI requires strict synchronization and timing accuracy between REC and RE: the clock received at the RE must be traceable to the main REC clock with an accuracy of 8.138 ns. This number is exactly a fraction of T_c = 260.416, in particular $T_c/32$.

• CPRI equipment must support an operating range of at least 10 km.

• The main requirements for CPRI transmission apart from the required bandwidth are delay and bit error rate (BER). CPRI links should operate with at most 5 μs delay contribution excluding propagation delay, and a maximum allowed BER of 10^{-12}. In addition, the frequency deviation from the CPRI link to the radio BS must be not larger than than 0.002 ppm.

DESIGN AND IMPLEMENTATION

CPRI defines three different logical connections between the REC and the RE: user plane data, control and management plane, and synchronization and timing. These three flows are multiplexed onto a digital serial communication line.

User Plane Data: Transported in the form of one or many in-phase and quadrature (IQ) data flows. Each IQ data flow reflects the radio signal, sampled and digitized, of one carrier at one independent antenna element, the so-called antenna carrier (AxC). In the particular case of LTE, an AxC contains one or more IQ samples for the duration of one UMTS chip ($T_c = 1/f_c = 260.416$ ns since f_c = 3.84 MHz).

Synchronization Data Used for Time and Frame Alignment: The interface shall enable the RE to achieve the frequency accuracy specified in 3GPP TS 45.10 [8]. The central clock frequency generation in the RE shall be synchronized to the bit clock of one of the ports connecting RE and REC. With 8B/10B or 64B/66B line coding, the bit clock rate of the interface shall be a multiple of 38.4 MHz in order to allow for a simple synchronization mechanism and frequency regeneration.

Control and Management: C&M data can be transmitted by either an in-band protocol (for time-critical signaling data) or higher-layer protocols not defined by CPRI. The inband protocol is used for synchronization and timing, and also for error detection/correction. This makes use of the line codings specified in IEEE 802.3 (line codes 8B/10B and 64B/66B). The physical layer is capable of detecting link failures and synchronization issues as a result of line code violations.

Vendor-Specific: CPRI reserves some time slots for the transmission of any vendor-specific data, allowing manufacturers to customize their solutions.
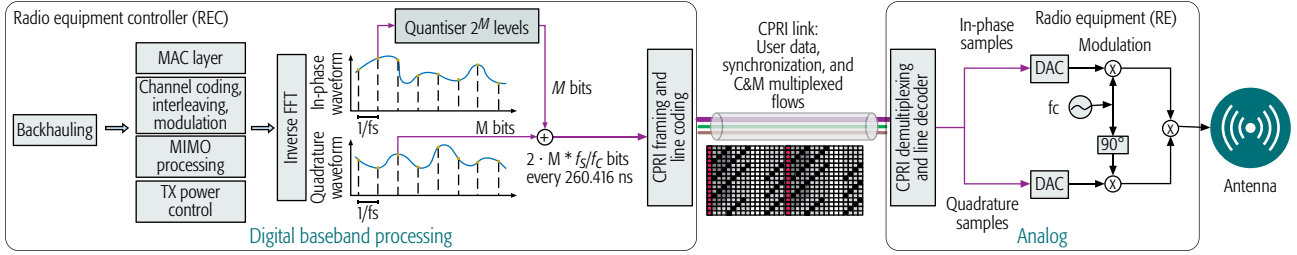
Figure 2. Conceptual explanation of REC/RE functional split.

TRANSMISSION OF USER PLANE DATA

The transmission of user plane data is based on the concept of an antenna carrier (AxC). Given that the LTE radio signal is first sampled and then quantized (Fig. 2), the amount of information carried by an AxC depends on two parameters:

- The sampling frequency f_s, which is a multiple of the nominal chip rate $f_c = 3.84$ MHz (Table 1).
- The number of bits M used in the quantization process of the I and Q radio signals. In E-UTRA, $M = 8, …, 20$ either DL or UL. Previous work [9] and actual field programmable gate array (FPGA) implementation of CPRI consider $M = 15$ for capacity efficiency.

For example, in a configuration with $M = 15$ b/sample, one AxC comprises $15 + 15 = 30$ b/IQ sample, which are transmitted in the following interleaved sequence:

$$I_0 Q_0 I_1 Q_1 … I_{M-1} Q_{M-1},$$

that is, from the least significant bit (LSB) to the most significant bit (MSB).

In CPRI, one basic frame is created and transmitted every $T_c = 260.41\overline{6}$ ns, which is based on the Universal Mobile Telecommunications System (UMTS) clock rate, that is, 3.84 MHz. This duration remains constant for all CPRI line bit rate options. As already indicated, this value of T_c is designed to transport one fast Fourier transform (FFT) sample for an LTE channel bandwidth of 2.5 MHz, two samples for the 5 MHz bandwidth, four samples for the 10 MHz channel, and so on.

A basic frame comprises $W = 16$ words ($w = 0, …, 15$) whereby the length T of each word depends on the CPRI line bit rate option (Table 2). The exact line bit rate values for each option are computed in the second column of Table 2. In all cases, the first word $w = 0$ is reserved for control, while the other 15 words are used to carry IQ data samples. For example, in CPRI option 1, there is room for 120 (= 15 words × 8 b/word) bits for transporting the IQ samples of several AxCs. Thus, in a configuration of $2M = 30$ b/AxC, one basic frame can carry up to 4 AxCs consisting of one sample each. This is a basic configuration for an antenna serving four sectors with 2.5 MHz LTE channel bandwidth. It is worth remarking that four 2.5 MHz AxCs carry about $4 \cdot 12 = 48$ Mb/s of actual LTE data, and are spread over 614.4 Mb/s after CPRI encapsulation; this is about 13 times higher bit rate.

CPRI defines a hierarchical framing with three layers (Fig. 3), chosen this way to match the framing numbers of the LTE FDD frame structure:

- Basic frame, of variable size, created and transmitted every $T_c = 260.416$ ns.
- Hyperframe, which is a collection of 256 basic frames. One hyperframe is created every $256 × T_c = 66.67$ μs, which is the OFDM symbol time in LTE. Thus, a hyperframe carries all the FFT samples required to decode the whole OFDM symbol.
- CPRI frame, which is a collection of 150 hyperframes. A CPRI frame is created every 10 ms and carries the digital samples of a whole LTE frame.

CONTROL AND MANAGEMENT, AND SYNCHRONIZATION

As noted before, the first word ($w = 0$) in every basic frame (control word) carries C&M information; thus, 256 control words are available per hyperframe. These 256 control words are organized into 64 subchannels of 4 control words each (Fig. 4). As shown, every control word can be addressed by a subchannel ID (0, …, 63).

Each subchannel belongs to one category out of seven:

Synchronization: The control word on the first basic frame (CW 0 in Fig. 4) is reserved to indicate the starting of a new hyperframe. This control word uses a special 8B/10B (K28.5) or 64B/66B (50h) code. The three remaining words in the synchronization subchannel (words 64, 128, and 192) are used to signal the hyperframe number and the node B frame number (BFN) for synchronization purposes with the LTE framing.

L1 In-Band Protocol: Subchannel 2 carries the necessary signaling required to set up the different C&M links, including starting up, resetting, and tearing down the CPRI link, and also to handle alarms at the PHY for different events such as loss of synchronization.

Slow C&M Link: The subchannels assigned to this category enable the transmission of high-level data link control (HDLC) frames. HDLC is a well-known layer 2 protocol providing basic functionalities such as flow control and error correction based on retransmission.

Ctrl_AxC: A Ctrl_AxC designates one AxC-specific control data stream. The mapping of Ctrl_AxCs to AxCs as well as the actual content of the control data bytes are not defined in CPRI but are vendor-specific.

Fast C&M Link: In addition to the slow C&M link, the operator of the CPRI link is provided

Option #	CPRI data rate (Mb/s)	Coding	T	Number of AxCs of channel bandwidth and bit rate required per AxC					
				1.25 MHz (76.8 Mb/s)	2.5 MHz (153.6 Mb/s)	5 MHz (307.2 Mb/s)	10 MHz (614.4 Mb/s)	15 MHz (921.6 Mb/s)	20 MHz (1228.8 Mb/s)
1	614.4	8B/10B	8	8	4	2	1	–	–
2	1228.8	8B/10B	16	16	8	4	2	1	1
3	2457.6	8B/10B	32	32	16	8	4	2	1
4	3072	8B/10B	40	40	20	10	5	3	2
5	4915.2	8B/10B	64	64	32	16	8	5	4
6	6144	8B/10B	80	80	40	20	10	6	5
7	9830.4	8B/10B	128	128	64	32	16	10	8
				(63.36 Mb/s)	(126.72 Mb/s)	(253.44 Mb/s)	(506.88 Mb/s)	(760.32 Mb/s)	(1013.76 Mb/s)
7A	8110.08	64B/66B	128	128	64	32	16	10	8
8	10137.6	64B/66B	160	160	80	40	20	13	10
9	12165.12	64B/66B	192	192	96	48	24	16	12

Table 2. Maximum number of AxC transported in a CPRI link, $M = 15$ bits.

with a fast C&M subchannel to transmit other control information. Such control frames are first encapsulated over Ethernet and then transmitted over this subchannel. Fragmentation and reassembly are needed. For this purpose, CW 194 carries a pointer to the CW in the hyperframe containing the first byte of the Ethernet frame (shown in Fig. 4 as pointer P).

Reserved for Future Use and Vendor-Specific.

CPRI FRONTHAUL DIMENSIONING IN C-RAN SCENARIOS

GENERAL DIMENSIONING GUIDELINES

Following the discussion earlier, the D-RoF transmission (i.e., sampling and quantization) of an AxC requires a data bit rate of $B_{AxC} = (2M) f_s$ b/s, expanded by factors 16/15 (15 words data, 1 word C&M) and either 10/8 or 66/64 (8B/10B or 66B/64B line coding, respectively). According to this, a 2.5 MHz LTE channel requires 153.6 Mb/s per AxC.

In this light, Table 2 shows the bit rate required per AxC for different LTE bandwidths and the maximum number of AxCs transported for standard CPRI bit rates. This table provides a good starting point for dimensioning fronthaul networks in C-RAN scenarios, and should be read as follows: CPRI option 6 (6144 Mb/s) can carry 80 AxCs @ 1.25 MHz LTE bandwidth, 40 AxC @ 2.5 MHz, or 5 AxC @ 20 MHz. On the other hand, if the LTE setup is fixed to a number of 3 sectors and 2×2 MIMO @ 10 MHz LTE bandwidth (i.e., 2×3 AxCs), a lookup in Table 2, column "10 MHz LTE bandwidth" reveals that at least CPRI option 5 is required to carry such a number of AxC.

USE CASE: CPRI DOWNLINK REQUIREMENTS FOR A FOUR-ANTENNA SITE, 2×2 MIMO, 20 MHz CHANNEL SCENARIO

Consider the four-antenna/four-sector scenario operating an LTE 2×2 MIMO channel of 20 MHz bandwidth depicted in Fig. 3a. This sce-nario requires the multiplexing and transmission of four AxC groups (one per sector), while each AxC group comprises two AxCs, as shown in the figure.

Figure 3b shows the amount of information carried in each AxC. As shown, one IQ sample ($2M = 30$ bits) is generated every $1/f_s$, where $f_s = 30.72$ MHz for 20 MHz LTE channels (Table 1). Thus, a total of $8 \times 30 = 240$ bits are generated every $1/f_s$. It is also worth remarking that $f_s = 30.72$ MHz is exactly $8f_c$; hence, 8 IQ samples are generated every $1/f_c = T_c = 260.41\overline{6}$ ns (i.e., 1920 IQ b/T_c total). This amount of information requires 8×1228.8 Mb/s = 9830.4 Mb/s (8B/10B assumed), which is CPRI option 7 in Table 2. Alternatively, CPRI option 7A is also suitable for carrying the same 8 AxCs @ 20 MHz LTE channel and even requires slightly less bandwidth since 64B/66B is used. In both cases, a 10 Gb/s Ethernet transceiver is suitable as a physical medium for this scenario.[2]

Figure 3c shows how the different AxC are grouped together and multiplexed over the line. The CPRI specification defines three mapping methods to multiplex different AxCs; we have chosen mapping method 3, which is backward compatible with previous CPRI specifications. Essentially, the IQ samples are arranged in order per AxC group (group 1 first, group 4 last) and interleaved within the group (30 bits AxC0, then 30 bits AxC1, then 30 bits AxC0 again, etc. for group 1).

Such ordering is then used to construct a CPRI basic frame (Fig. 3d) noting that one word for C&M is added ahead of the 1920 data bits. One basic frame is constructed this way every $260.41\overline{6}$ ns; 256 basic frames form a hyperframe (66.67 μs), which includes the information of one LTE OFDM symbol; and 150 hyperframes form a super frame, which is synchronized with the 10 ms LTE frame (Fig. 3e).

Other scenarios would follow the same guidelines as before. For instance, the same configu-

[2] It is worth noting that this configuration requires daisy chaining of the different REs. If this is not possible, a potential configuration may use 4 CPRI-3 (2457.3 Mb/s) links.
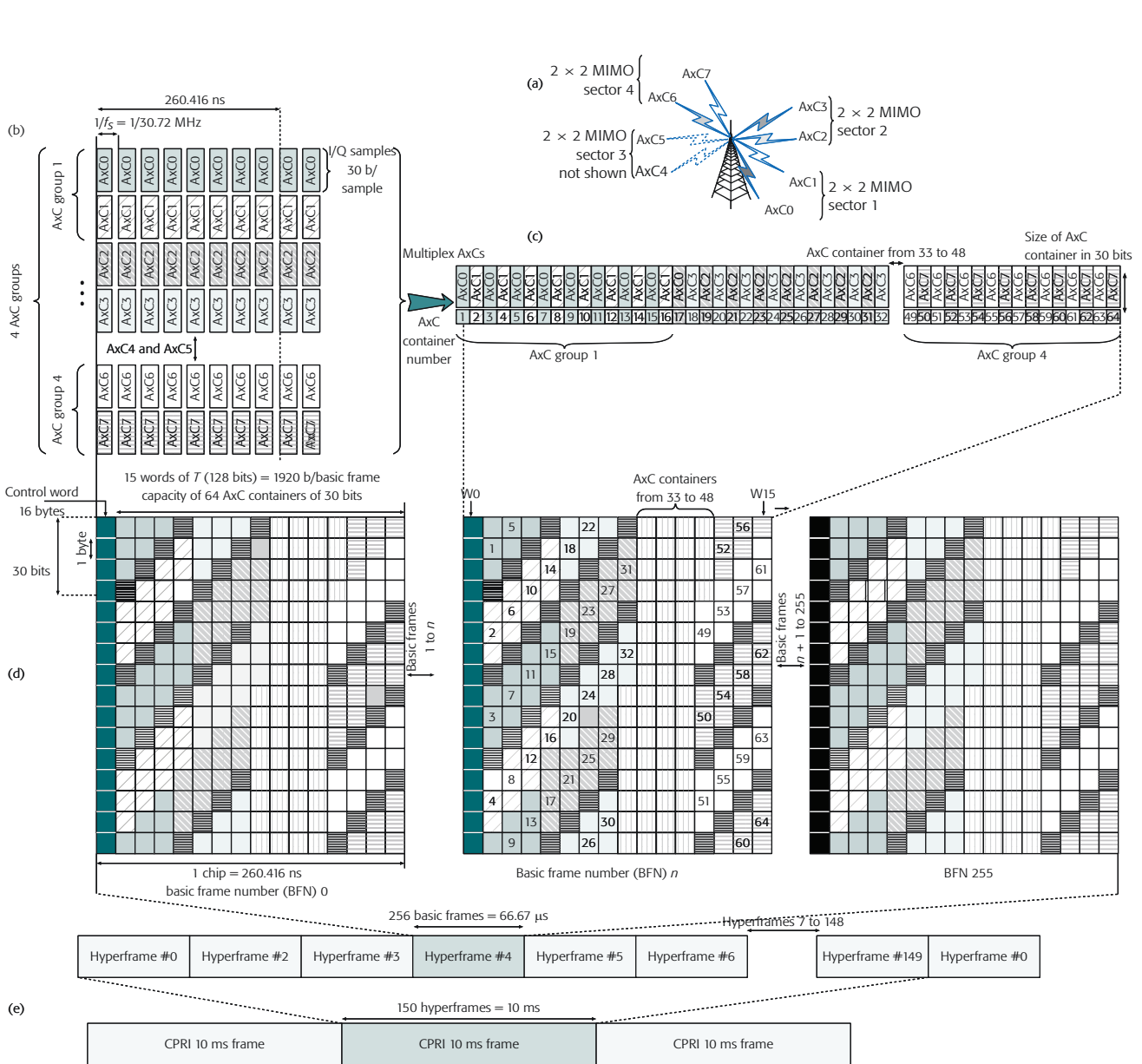
Figure 3. CPRI multiplexing of AxC data in a 2 × 2 MIMO 20 MHz channel use case: a) scenario; b) AxC generation; c) AxC arrangement and serialization; d) basic frame construction; e) hyperframes and 10 ms CPRI frame.

ration in a 4 × 4 MIMO scenario would require the same sampling frequency f_s, but the data rate would double since we now have 4 AxC groups with 4 AxCs per group, that is, a total of 16 AxCs. The arrangement of Fig. 3c would be the same for the AxC group (group 1 first, group 4 last), but AxCs within the group would alternate (AxC0, AxC1, AxC2, AxC3, AxC0 again, and so on for group 1).

SUMMARY, CHALLENGES AND FUTURE RESEARCH

This work has provided a short overview of CPRI, including concept, design, specification, and use case in an LTE C-RAN-based environment. The concept of C-RAN has recently appeared in the market, and the idea of separating RECs (BBUs) from REs (RRHs) is gaining traction in the mobile network industry.

On the research side, there is a common con-sensus on the key challenges of CPRI technology [10]. First, the amount of bandwidth required to transmit the radio signal is simply overwhelming for LTE. Moreover, the upcoming 5G RANs, where 100 MHz channels with massive MIMO are envisioned, may require several tens or even hundreds of gigabits per second capacity in the fronthaul [11]. As an example, an 8 × 8 MIMO antenna covering four sectors produces 32 AxCs, which translate into around 32 Gb/s for 20 MHz bandwidth channels. In the case of 100 MHz LTE channels, this same scenario requires five times (i.e., 160 Gb/s) the previous CPRI band-width.

Second, CPRI is a serial CBR interface with new frames transmitted every $T_c = 260.416$ ns. This, together with the low-latency and strict syn-chronization requirements demanded, makes it very challenging to have CPRI and other traf-fic sources over the same link. Recent studies have approached this problem focusing on band-
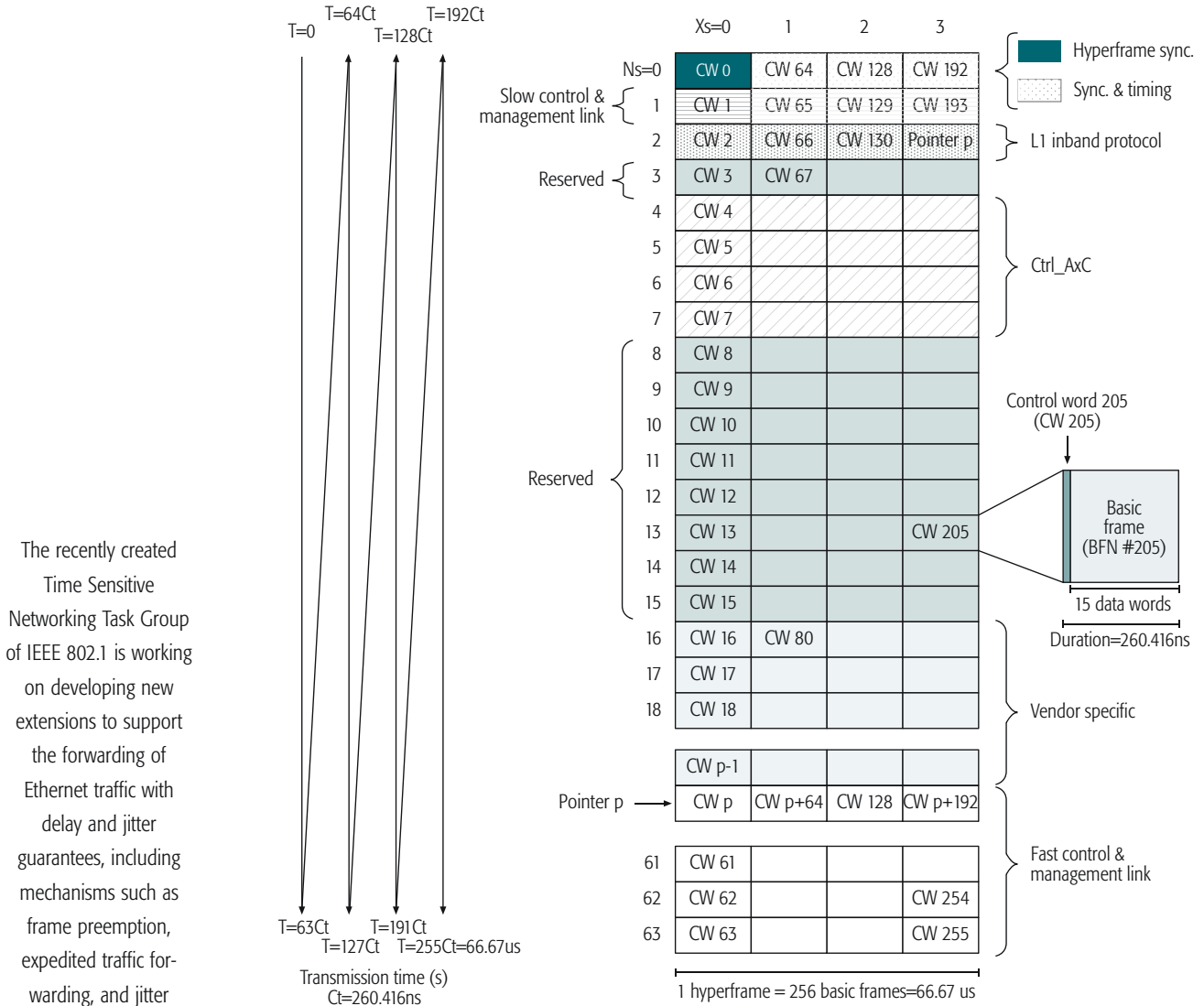
T=0 T=64Ct T=128Ct T=192Ct

	Xs=0	1	2	3
Ns=0	CW 0	CW 64	CW 128	CW 192
1	CW 1	CW 65	CW 129	CW 193
2	CW 2	CW 66	CW 130	Pointer p
3	CW 3	CW 67		
4	CW 4			
5	CW 5			
6	CW 6			
7	CW 7			
8	CW 8			
9	CW 9			
10	CW 10			
11	CW 11			
12	CW 12			
13	CW 13		CW 205	
14	CW 14			
15	CW 15			
16	CW 16	CW 80		
17	CW 17			
18	CW 18			
	CW p-1			
Pointer p →	CW p	CW p+64	CW 128	CW p+192
61	CW 61			
62	CW 62			CW 254
63	CW 63			CW 255

Slow control & management link — Reserved — Reserved — Pointer p

Legend: Hyperframe sync. — Sync. & timing — L1 inband protocol — Ctrl_AxC — Control word 205 (CW 205) — Basic frame (BFN #205) — 15 data words — Duration=260.416ns — Vendor specific — Fast control & management link

T=63Ct T=127Ct T=191Ct T=255Ct=66.67us

Transmission time (s) Ct=260.416ns

1 hyperframe = 256 basic frames=66.67 us

Figure 4. CPRI multiplexing of C&M channels in the hyperframe. C&M information is carried in the control word (CW) of each CPRI frame.

width compression techniques. For example, the authors in [12] claim to provide about 1/5 compression ratios within the 5 μs delay budget allowed by CPRI, thus significantly reducing the link load.

Bandwidth compression is indeed a starting point toward the packetization of CPRI data, via Ethernet framing, for instance. However plain Ethernet is asynchronous and best effort, and therefore not suitable as such for the transport of CPRI traffic. In this light, the recently created Time Sensitive Networking (TSN) Task Group of IEEE 802.1[3] is working on developing new extensions to support the forwarding of Ethernet traffic with delay and jitter guarantees, including mechanisms such as frame preemption, expedited traffic forwarding, and jitter reduction techniques, mainly buffering [13].

In addition, the use of synchronous Ethernet seems mandatory in multihop scenarios [14]. Nevertheless, although high-precision timing protocols over Ethernet exist (see IEEE 1588v2), their accuracy is in the range of a few hundred nanoseconds, while CPRI requires at most tens of nanoseconds between REC and RE. New approaches using frequency adjustable oscillators or GPS signals are under study to solve this issue.

Finally, both research projects and standardization bodies (e.g., IEEE 1904.3 Standard for Radio over Ethernet Encapsulation and Mappings[4]) are exploring the possible gains of redefining the RE/REC functional split of C-RAN in the next-generation networks [15]. Examples include the decoupling of fronthaul bandwidth and antenna number by moving antenna related operations to the RE (DL antenna mapping, FFT, etc.), or enabling traffic-dependent bandwidth adaptation by effectively coupling fronthaul bandwidth with the actual traffic served in the cell. The latter relies on the fact that many cell processing functions do not depend on the number of users, including FFT, cyclic prefix addition/removal, synchronization signals, and so on. More information about this novel approach can be found in [7].

Acknowledgments

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The use of Synchronous Ethernet seems mandatory in multi-hop scenarios. Nevertheless, although high-precision timing protocols over Ethernet exist, their accuracy are in the range of few hundred nanoseconds, while CPRI requires at most tens of nanoseconds between REC and RE.

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