An overview of the CPRI specification and its application to C-RAN based LTE scenarios

Antonio de la Oliva*, José Alberto Hernández*, David Larrabeiti*, Arturo Azcorra*†
*Universidad Carlos III de Madrid, Spain
Email: {aoliva, jahgutie, dlarra, azcorra}@it.uc3m.es
†IMDEA Networks Institute, Madrid, Spain
Email: arturo.azcorra@imdea.org

***Abstract*— The Common Public Radio Interface (CPRI) specification has been introduced to enable the communication between Radio Equipment and Radio Equipment Controllers, and is of particular interest for Mobile Operators (MNO) willing to deploy their networks following the novel Cloud Radio Access Networks (C-RAN) approach. In such a case, CPRI provides an interface for the interconnection of Remote Radio Heads (RRH) with Base-Band Unit (BBU), 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.**

***Index Terms*— C-RAN; fronthaul; LTE PHY; CPRI; 5G.**

I. Introduction and Motivation

Mobile Network Operators (MNO) have realised that the Cloud Infrastructure 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 showed 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% savings in OPEX and CAPEX respectively [1].

The C-RAN approach advocates for the separation between the radio elements of the base station (called Remote Radio Heads, RRH) and the elements processing the base band signal (called Base Band Units, BBU) which are centralised in a single location or even virtualised into the cloud. This approach benefits from simpler radio equipment at the network edge, easier to operate and cheaper to maintain, while the main RAN intelligence (BBUs) is centralised 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-synchronised network, the so-called fronthaul. Such critical requirements are currently met with fibre optics [2], [3].

The C-RAN approach has some some clear benefits with respect to traditional integrated base stations (BS). First, the cost of deploying RRHs decreases considerably, since the installation footprint is much smaller. RRHs do not need for any refrigeration or costly on-site constructions; thus shortening time for deployment compared with traditional integrated BSs. On the other hand, BBUs can be aggregated and further virtualised 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 the reduction of the interference between different radio transmissions and improving its performance. This further enables denser RRH deployments than traditional ones since interference among base stations can be better mitigated [4].

A number of radio equipment manufacturers have defined two main specifications for the transport of fronthaul traffic, namely the Common Public Radio Interface (CPRI) [5] and the Open Base Station Architecture Initiative (OBSAI). Both solutions are based on the implementation of Digital Radio over Fibre (D-RoF) concept, whereby the radio signal is sampled and quantised, and after encoding, transmitted towards 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 to fronthaul dimensioning in realistic LTE scenarios. We also provide some interesting open research challenges and current initiatives to bring the C-RAN concept to the next-generation 5G mobile network. Accordingly, Section II briefly reviews the LTE PHY specifications required to understand the design of CPRI. Section III introduces the top-level fronthaul network requirements demanded by CPRI and its main features including the user plane data, control & management and synchronisation information multiplexing. Section IV provides an application example of CPRI in a realistic LTE scenario. Finally, Section V concludes this work providing a number of open research issues and challenges regarding CPRI and the fronthaul.

II. 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 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, minimising 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 downlink with a 20 MHz channel and a 4x4 MIMO configuration can provide up to 300 Mbps of user-plane data. The uplink peak data rate is 75 Mbps.

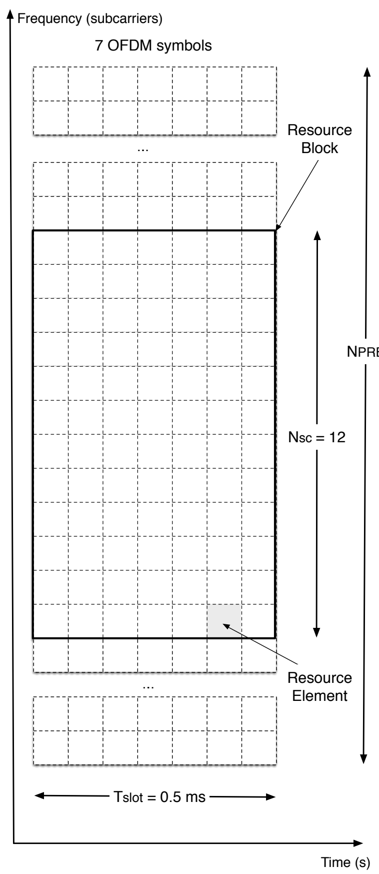

Fig. 1. Downlink Resource Grid defined in LTE

LTE defines a Generic Frame Structure that applies to both DL and UL for Frequency Division Duplex (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 OFDM symbols (7 for the short CP or 6 for the long CP) with $T_{symbol} = 66.67\ \mu s$.

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 the so-called Physical Resource Blocks (PRBs), which are the smallest bandwidth unit (180 KHz) assigned by the base station scheduler (see Fig. 1). Thus, different transmission bandwidths use various PRBs per time-slot, ranging from $N_{PRB} = 6$ to 100, as shown in Table I.

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-QAM modulation (6 bit/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 $\times$ 7 OFDM symbols $\times$ 6 bit/symbol), and the resulting data rate is approximately 12 Mbps. The effective data rate is actually less than this value since some Resource Elements of the PRB are reserved for control and signalling. It is also worth noting that there is one resource grid for each transmitting antenna; in other words, in a 2x2 MIMO configuration the value above doubles (24 Mbps).

In order to recover the whole data transmitted, the receiver must take N_{FFT} samples per OFDM symbol (T_{symbol}) as specified in Table I. In the example above, the receiver must take $N_{FFT} = 256$ samples per OFDM symbol (66.67 μs) in order to recover the data transmitted in such $B_{tx} = 2.5$ 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 $T_s = 1/f_s = 260.41\overline{6}$ ns.

It is worth highlighting the importance of the $f_s = 3.84$ MHz sampling reference value of LTE FDD, since the timing and synchronisation 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 $1/f_c = 260.41\overline{6}$ ns to carry the sampled digitised OFDM symbol, thus completely aligned with the LTE time reference.

III. Overview of CPRI

A. 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 digitised radio information between REC and RE.

Fig. 2 shows the functional split between REC and RE as defined in the CPRI specification (downlink). As shown in the figure, all the operations above the physical layer, and most of the ones of the physical layer 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 centralisation of all the signal processing functions in the BBU simplifies the adoption of cooperative techniques such as Cooperative Multipoint (CoMP) which require advanced processing of the radio signal of several RRHs simultaneously.

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

Tx BW (B_{tx})	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 freq ($f_s = 15KHz \times N_{FFT}$)	1.92 MHz ($1/2 \times 3.84MHz$)	3.84 MHz	7.68 MHz ($2 \times 3.84MHz$)	15.36 MHz ($4 \times 3.84MHz$)	23.04 MHz ($6 \times 3.84MHz$)	30.72 MHz ($8 \times 3.84MHz$)
Subcarriers/PRB (N_{sc})	12					
OFDM symbols (N_{CP})	7/6 (Short/Long CP)					
Modulation	QPSK, 16-QAM, 64-QAM					
MIMO Configurations	4x2, 2x2, 1x2, 1x1					
I/Q data rate (Gbps) per AxC	0.0576	0.1152	0.2304	0.4608	0.6912	0.9216

TABLE I

DOWNLINK OFDM MODULATION PARAMETERS AND CPRI BANDWIDTH REQUIRED FOR THE CASE OF M=15 BITS PER SAMPLE

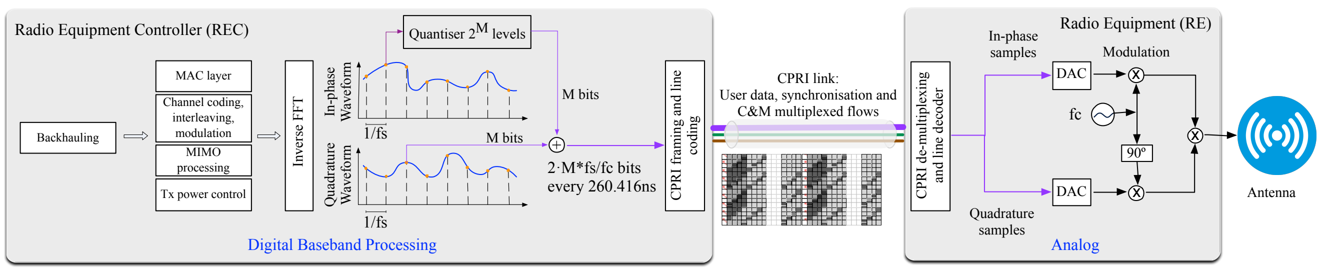

Fig. 2. Conceptual explanation of REC/RE functional split

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: 3GPP UTRA FDD, WiMAX, 3GPP E-UTRA (LTE) and 3GPP GSM/EDGE. This article is only focused 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 multi-hop options to carry CPRI data over multiple hops. For example, CPRI supports natively the multiplexing of two CPRI-1 (614.4Mbps) into a single CPRI-2 (1228.8Mbps) frame through daisy chaining of the REs.
- CPRI requires strict synchronisation 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 $T_c = 260.41\overline{6}$, 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 base station must be not larger than than 0.002 ppm.

B. Design and implementation

CPRI defines three different logical connections between the REC and the RE, namely: (i) user plane data, (ii) control & management plane, and (iii) synchronisation and timing. Such 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 digitised 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 ($T_c = 1/f_c = 260.41\overline{6}$ 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 the 3GPP TS 45.10 [8]. The central clock frequency generation in the RE shall be synchronised 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 synchronisation mechanism and frequency regeneration.
- Control and Management data can be transmitted either by an in-band protocol (for time critical signalling data) or by higher-layer protocols not defined by CPRI. The inband protocol is used for synchronisation 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 synchronisation 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 customise their solutions.

C. Transmission of user plane data

The transmission of user plane data is based on the concept of Antenna Carrier (AxC). Given that the LTE radio signal is first sampled and then quantised (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 (see Table I).
- The number of bits M used in the quantisation process of the I and Q radio signals. In E-UTRA, $M = 8, \ldots, 20$ either DL or UL. Previous work [9] and actual FPGA implementation of CPRI consider $M = 15$ for capacity efficiency.

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

$$I_0 Q_0 I_1 Q_1 \ldots I_{M-1} Q_{M-1}$$

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 UMTS clock rate, namely 3.84 MHz. Such duration remains constant for all CPRI line bit rate options. As already indicated, this value of T_c is designed to transport one FFT sample for an LTE channel bandwidth of 2.5 MHz, two samples for the 5 MHz bandwidth, 4 samples for the 10 MHz channel, etc.

A Basic Frame comprises W = 16 words ($w = 0, \ldots, 15$) whereby the length T of each word depends on the CPRI line bit rate option (see Table II). The exact line bit rate values for each option are computed in the second column of Table II. 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 x 8 bit/word) bits for transporting the IQ samples of several AxC. Thus, in a configuration of $2M = 30$ bits per AxC, one basic frame can carry up to 4 AxC consisting of one sample each one. This is a basic configuration for an antenna serving four sectors with 2.5MHz LTE channel bandwidth. It is worth remarking that four 2.5 MHz AxCs carry about $4 \cdot 12 = 48$ Mbps of actual LTE data, and are spread over 614.4 Mbps after CPRI encapsulation; this is about 13 times more bitrate.

CPRI defines a hierarchical framing with three layers (see Fig. 4), chosen this way to match the framing numbers of the LTE FDD Frame Structure:

- Basic Frame, of variable size, created and transmitted every $T_c = 260.41\overline{6}$ ns.
- Hyperframe, which is a collection of 256 Basic Frames. One hyperframe is created every $256 \times T_c = 66.67\ \mu s$ 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.

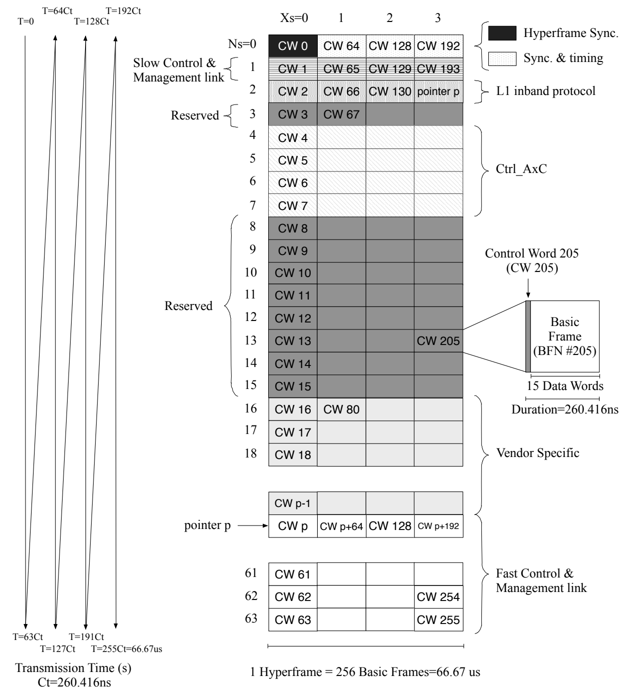

Fig. 3. CPRI multiplexing of C&M channels in the hyperframe. C&M information is carried in the control word (CW) of each CPRI frame.

D. Control & Management (C&M), and Synchronisation

As noted before, the first word ($w = 0$) in every Basic Frame (control word) carries Control and Management (C&M) information, thus 256 control words are available per hyperframe. These 256 control words are organised into 64 subchannels of 4 control words each, see Fig. 3. As shown, every control word can be addressed by a sub channel ID $(0, \ldots, 63)$.

Each sub channel belongs to one category out of seven:

- Synchronisation: The control word on the first Basic Frame (CW0 in Fig. 3) 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 synchronisation subchannel (words 64, 128 and 192) are used to signal the hyperframe number and the Node B Frame Number (BFN) for synchronisation purposes with the LTE framing.
- L1 in-band protocol: Subchannel no. 2 carries the necessary signalling required to setup the different C&M links, including start up, reset and tear down the CPRI link, and also to handle alarms at physical layer for different events such as loss of synchronisation.
- 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.

Option #	CPRI Data Rate (Mbps)	Coding	T	Number of AxCs of Channel Bandwidth and Bitrate 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 II

MAXIMUM NUMBER OF AXC TRANSPORTED IN A CPRI LINK, $M = 15$ BITS

- Fast C&M link: In addition to the Slow C&M link, the operator of the CPRI link is provided with a Fast C&M subchannel to transmit other control information. Such control frames are first encapsulated over Ethernet and then transmitted over this sub channel. Fragmentation and re-assembly is needed. For this purpose, CW 194 carries a pointer to the control word in the hyperframe containing the first byte of the Ethernet frame (shown in Fig. 3 as pointer P).
- Reserved for future use and Vendor Specific.

IV. CPRI FRONT HAUL DIMENSIONING IN C-RAN SCENARIOS

A. General dimensioning guidelines

Following the discussion of Section III-C, the D-RoF transmission (i.e. sampling and quantisation) of an AxC requires a data bit rate of $B_{\text{AxC}} = (2M)f_s$ bit/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 II shows the bitrate required per AxC for different LTE bandwidths and the maximum number of AxC transported for standard CPRI bit rates. This table provides a good starting point for dimensioning front haul networks in C-RAN scenarios, and should be read as follows: For example CPRI option 6 (6144 Mbit/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 2x2 MIMO @ 10 MHz LTE bandwidth (i.e. 2×3 AxC), then a lookup on Table II column "10 MHz LTE bandwidth" reveals that at least CPRI option 5 is required to carry such number of AxC.

B. Use case: CPRI downlink requirements for a four-antenna site, 2x2 MIMO, 20MHz channel scenario

Consider the four-antenna/four-sector scenario operating an LTE 2x2 MIMO channel of 20 MHz bandwidth, as depicted in Fig. 4 (a). This scenario requires the multiplexing and transmission of four AxC Groups (one per sector), while each AxC Group comprises two AxC, as shown in the figure.

Fig. 4 (b) 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 (see Table I). So, 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 $8f_c$, thus 8 IQ samples are generated every $1/f_c = T_c = 260.41\overline{6}$ ns (i.e. 1920 IQ bits per 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 II. Alternatively, CPRI option 7A is also suitable for carrying such 8 AxCs @ 20 MHz LTE channel and even requires slightly less bandwidth since 64B/66B is used. In both cases, a 10Gb/s Ethernet transceiver is suitable as a physical media for this scenario.[2]

Fig. 4 (c) shows how the different AxC are grouped together and multiplexed over the line. The CPRI specification defines three mapping methods to multiplex different AxC, we have chosen mapping method 3 which is backwards 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. 4 (d)) 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 ($66.67 \mu s$) which includes the information of one LTE OFDM symbol; and 150 Hyperframes form a super frame which is synchronized with the 10ms LTE frame (Fig. 4 (e)).

Other scenarios would follow the same guidelines as before. For instance, same configuration in a 4x4 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 AxC per group, i.e. a total of 16 AxC. The arrangement of Fig. 4 (c) would be the same for the AxC Group (Group 1 first, Group 4 last) but AxC within the group would alternate (AxC0, AxC1, AxC2, AxC3, AxC0 again and so on for Group 1).

[2]It is worth noting that this configuration requires daisy chaining of the different REs. In case this is not possible, a potential configuration may use 4 CPRI-3 (2457.3 Mbps) links.

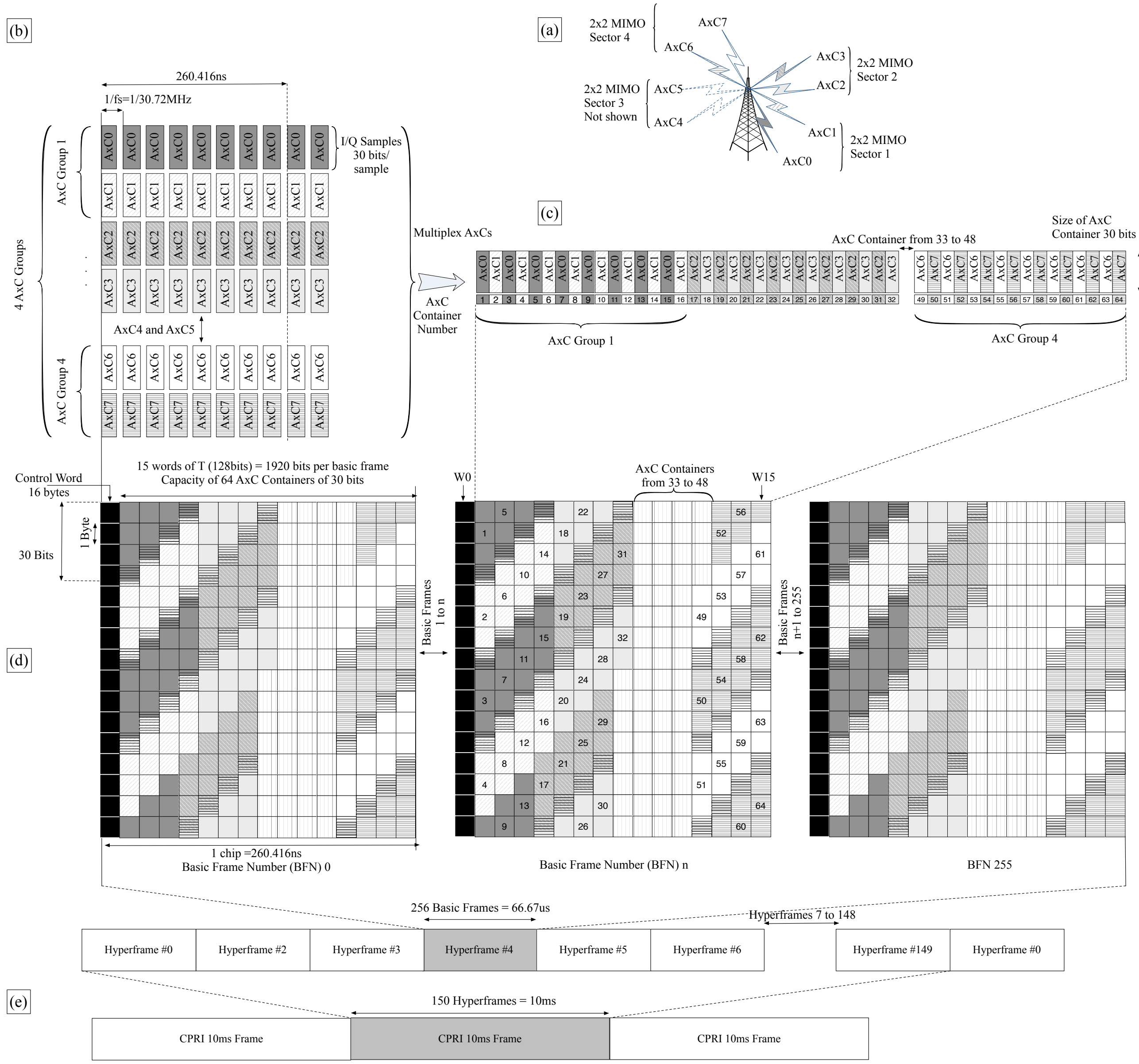

Fig. 4. CPRI multiplexing of AxC data in a 2x2 MIMO 20 MHz channel use case. (a) Scenario; (b) AxC generation; (c) AxC arrangement and serialisation; (d) Basic Frame construction; (e) Hyperframes and 10ms CPRI frame.

V. 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 consensus 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 of 5G RANs, where 100 MHz channels with massive MIMO are envisioned, may require several tens or even hundreds of Gbps capacity in the fronthaul [11]. As an example, an 8x8 MIMO antenna covering 4 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 the previous CPRI bandwidth.

Second, CPRI is a serial CBR interface with new frames transmitted every $T_c = 260.41\overline{6}$ ns. This, together with the low-latency and strict synchronisation requirements demanded makes it very challenging to have CPRI and other traffic sources over the same link. Recent studies have approached this problem focusing on bandwidth 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 towards the packetisation of CPRI data, via Ethernet framing for instance. However plain Ethernet is asynchronous and best effort, 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 multi-hop scenarios [14]. Nevertheless, although high-precision timing protocols over Ethernet exist (see IEEE 1588v2), their accuracy are in the range of 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 standardisation 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 (e.g., 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, for instance FFT, Cyclic prefix addition/removal, synchronisation signals, etc. More information about this novel approach can be found in [7].

Acknowledgements

The authors would like to acknowledge the support of projects CRAMnet (grant no. TEC2012-38362-C03-01) and EU H2020 Xhaul Project (grant no. 671598) to the development of this work.

References

[1] "C-RAN: the road towards green RAN," *China Mobile White Paper, v2*, 2011.

[2] A. Lometti, C. Addeo, I. Busi, and V. Sestito, "Backhauling solutions for LTE networks," in *Transparent Optical Networks (ICTON), 2014 16th International Conference on*, July 2014, pp. 1–6.

[3] A. Pizzinat, P. Chanclou, F. Saliou, and T. Diallo, "Things you should know about fronthaul," *IEEE/OSA J. Lightwave Technology*, 2015.

[4] R. Irmer, H. Droste, P. Marsch, M. Grieger, G. Fettweis, S. Brueck, H.-P. Mayer, L. Thiele, and V. Jungnickel, "Coordinated multipoint: Concepts, performance, and field trial results," *IEEE Communications Magazine*, vol. 49, no. 2, pp. 102–111, 2011.

[5] Specification, CPRI, "V6.1 Common Public Radio Interface (CPRI); interface specification, july, 2014, 129 pages, ericsson ab, huawei technologies col ltd, nec corporation, nortel networks sa and siemens networks gmbh & co," *Ltd, NEC Corporation, Nortel Networks SA, Siemens Networks GmbH & Co. KG, Ericsson AB and Huawei Technologies Co Ltd*.

[6] M. Nahas, A. Saadani, J. Charles, and Z. El-Bazzal, "Base stations evolution: Toward 4G technology," in *Telecommunications (ICT), 2012 19th International Conference on*. IEEE, 2012, pp. 1–6.

[3]`http://www.802tsn.org/`
[4]`http://www.ieee1904.org/3/`

[7] D. Wubben, P. Rost, J. S. Bartelt, M. Lalam, V. Savin, M. Gorgoglione, A. Dekorsy, and G. Fettweis, "Benefits and Impact of Cloud Computing on 5G Signal Processing: Flexible centralization through cloud-RAN," *IEEE Signal Processing Magazine*, vol. 31, no. 6, pp. 35–44, Oct. 2014.

[8] 3GPP, "3GPP TS 45.010: Radio subsystem synchronization," *3GPP Technical Specification*, vol. Release 10, V10.1.0, 2011.

[9] C. F. A. Lanzani, L. Dittmann, and M. S. Berger, "4G mobile networks: An analysis of spectrum allocation, software radio architectures and interfacing technology," Ph.D. dissertation, Technical University of Denmark, Department of Photonics Engineering.

[10] A. Saadani, M. El Tabach, A. Pizzinat, M. Nahas, P. Pagnoux, S. Purge, and Y. Bao, "Digital radio over fiber for LTE-advanced: Opportunities and challenges," in *Optical Network Design and Modeling (ONDM), 2013 17th International Conference on*. IEEE, 2013, pp. 194–199.

[11] J. E. Mitchell, "Integrated wireless backhaul over optical access networks," *IEEE/OSA J. Lightwave Technology*, vol. 32, no. 20, pp. 3373–3382, Oct. 2014.

[12] B. Guo, W. Cao, A. Tao, and D. Samardzija, "CPRI compression transport for LTE and LTE-A signal in C-RAN," *2013 8th International Conference on Communications and Networking in China (CHINACOM)*, vol. 0, pp. 843–849, 2012.

[13] T. Wan and P. Ashwood, "A performance study of CPRI over Ethernet." [Online]. Available: http://www.ieee1904.org/3/meeting_archive/2015/02/tf3_1502_ashwood_1a.pdf

[14] J. Aweya, "Implementing Synchronous Ethernet in telecommunication systems," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 2, pp. 1080–1113, Second Quarter 2014.

[15] P. Rost, C. Bernardos, A. Domenico, M. Girolamo, M. Lalam, A. Maeder, D. Sabella, and D. Wubben, "Cloud technologies for flexible 5G radio access networks," *IEEE Communications Magazine*, vol. 52, no. 5, pp. 68–76, May 2014.