Microprocessors and Microsystems 000 (2016) 1–11

Contents lists available at ScienceDirect

Microprocessors and Microsystems

journal homepage: www.elsevier.com/locate/micpro

A flexible physical layer and fronthaul research testbed for C-RAN

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ARTICLE INFO

Article history:
Received 29 December 2015
Revised 6 July 2016
Accepted 6 September 2016
Available online xxx

Keywords:
C-RAN
Software-Defined radio
FPGA
BBU
Fronthaul
RRH
CPRI
Radio over fiber

ABSTRACT

Mobile networks are subject to an explosive increase in data traffic, in a context of continuous mobility and more stringent levels of QoS, which imposes demanding requirements to telecommunication networks. To cope with this trend, a novel paradigm of radio access networks, known as C-RAN, is being developed, where the physical layer processing is also shifted from the edges of the network to a centralized location. C-RAN provides important benefits and will be one of the cornerstones of 5G communication systems. However, some architectural and implementation tradeoffs need to be further evaluated. Moreover, the modularity and extensibility of research platforms supporting C-RAN is still very restrictive. This paper presents a laboratorial platform aimed for the development and trial of C-RAN compliant features. The proposed testbed is very modular and flexible and it is intended to provide a cost-effective emulation and physical layer implementation platform for the main C-RAN modules, namely the BBU, the fronthaul and the RRHs. Based on open FPGA platforms, it features a high level of flexibility in terms of configurations, waveforms and interfaces, and includes all the components required to build an open and complete C-RAN compliant base station. It is mainly used for the experimentation and evaluation of next generation wireless communication systems, including new fronthaul protocols and interfaces as well as 5G waveforms. It integrates a 25 km optical fronthaul, a software defined multi-mode and multi-band RF front-end and a digital radio compression algorithm associated with the optical fronthaul. The inclusion of low-latency (de)compression algorithms was of paramount importance in order to achieve a 50% reduction in terms of fronthaul bandwidth.

1. Introduction

The convergence of fixed transport networks, based on high-speed optical infrastructures and broadband spectrally efficient wireless components has been identified as a key enabler of future access networks. The next generation of wireless systems (5G) should fulfill several goals, among which: provision of true broadband wireless access and enhanced system capacity, when compared with current third (3G) and fourth (4G) generation networks. A traditional cellular network is built with many stand-alone Base Stations (BSs), each one covering a cell and processing and transmitting its own signal to and from the mobile terminals. The issues regarding the growing complexity of BSs, the need for cooling, the increasing number of BSs for improved coverage and the difficulties in the acquisition of sites has led to some rethinking of the cellular concept, whose main trends are currently converging to a new paradigm for the Radio Access Network (RAN). Cloud Radio Access Network (CRAN) has been defined in several different ways, but essentially designates a network architecture where several distributed Remote Radio Heads (RRHs) with reduced complexity are linked to a central or Base Band Unit (BBU) at which Radio Access Technology (RAT) specific L3/L2/L1 signal processing (i.e. modulation/demodulation, coding/decoding, error correction, among others) is performed.

The connection between the RRHs and the BBU is established through a high capacity network link, named fronthaul, typically supported by an optical infrastructure (depicted in Fig. 1). Due to its centralized scheme, CRAN will enable technologies such as cloud processing, resource virtualization and cooperative radio [9].

CRAN brings relevant advantages when compared to nowadays RAN infrastructures. Firstly, by deploying less complex access points than current BSs, operators can reduce their operational expenses, namely due to air conditioning and site rent. On the other hand, traditional BSs are designed to deal with the maximum

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http://dx.doi.org/10.1016/j.micpro.2016.09.001

Please cite this article as: J. Santos et al., A flexible physical layer and fronthaul research testbed for C-RAN, Microprocessors and Microsystems (2016), http://dx.doi.org/10.1016/j.micpro.2016.09.001

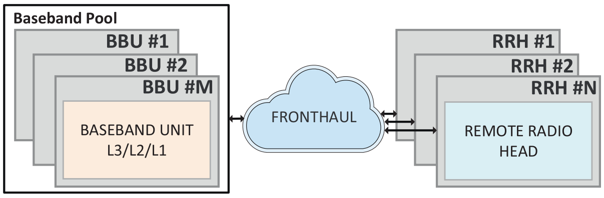

Fig. 1. Typical Centralized RAN scheme.

users/traffic load, which may occur sporadically at specific moments of the day. However, during the other periods, the unused capacity cannot be shared with other locations. In turn, CRAN allows flexible processing capacity, sharing it between BBUs according to real-time demands, thanks to the resource pool at the centralized site. Furthermore, Cloud-based technologies are the main flag of CRAN enabling the creation of a layer of abstraction from physical resources with real-time requirements. In line with the previous points, cooperative radio methods such as Coordinated Multi-Point (CoMP), which was introduced by 3GPP - Release 11 for Het-Nets, are enhanced by the CRAN topology. Based on Coordinated Scheduling/Beamforming (CSCB) techniques and Joint Processing (JP), CoMP is able to improve spectral efficiency and reduce inter-cell interference [9].

However, the development and implementation of the CRAN concept imposes several challenges that must be conveniently addressed in order to demonstrate clearly the advantages of this new RAN paradigm. For these purposes, it is fundamental the availability of open prototyping platforms and demonstrators. In this sense, this paper presents a CRAN testbed that performs the basic BBU-RRH interaction, featuring a high level of flexibility, allowing to add, develop and evaluate CRAN compliant features and design decisions. In particular, the following features can be independently configured and evaluated:

- New (5G) waveforms in addition to conventional 4G waveforms;
- Innovative fronthaul interfaces, such as Radio over Ethernet as an evolution of the conventional Common Public Radio Interface (CPRI);
- Alternative digital radio compression algorithms with different trade-offs in terms of complexity, latency and compression ratios;
- Novel Radio Frequency (RF) front-ends with improved bandwidth, sensitivity, frequency bands and other keys Figures of Merit (FoM).

The main reason for the development of this prototyping platform was the lack of open and modular platforms mainly due to closed commercial equipments or interoperability issues resulting from vendor-specific protocols or extensions. The presented testbed provides multi-band and multi-RAT compliance due to the utilization of standard interfaces, software defined radio approaches and implementation based on reconfigurable platforms.

2. Fronthaul approaches and concepts

As already mentioned in the introduction, a CRAN-based architecture implies two main elements geographically distributed: a BBU (or a pool of BBUs) and RRHs. Traditionally, both BBU and RRH modules feature an industry standard interface, such as CPRI, for the compliance of the mobile fronthaul transceivers produced by a third party supplier [12]. This interface provides the User, Control & Management (C&M) and Synchronization planes with flexible RAT support (2G/3G/4G). The CPRI specification defines the Radio Equipment Control (REC) as the element with, at least, one master port and the Radio Equipment (RE) with, at least, one Slave port. REC is the CPRI name for the BBU, while RE corresponds to the RRH. Thus, the REC is responsible for the BS control and monitoring, baseband signal processing, as well as core network interface (known as backhaul). In turn, the RE, is the entity that implements the conversion between digital and analog domains, as well as the signal filtering and amplification. User Plane is used to transfer waveform information based on In phase/Quadrature (I/Q) data, characterized by a given bandwidth and, possibly, a Multiple-Input Multiple-Output (MIMO) scheme. The purpose of C&M data is to send configuration commands from the controller unit (typically a BBU) and to receive status from remote devices. Lastly, the Synchronization flow is used to transfer timing information between nodes. In a Master device, timing is generated locally, while, in the Slaves, that information is recovered from the CPRI link and then used for air interface timings.

2.1. Challenges

Although CRAN may improve wireless system's efficiency and performance, some barriers related to field deployment are being studied and optimized. In general, operators may have to invest in order to replace incompatible equipment or legacy infrastructures. On the other hand, the fronthaul technology, including the interfaces, protocols and physical layer infrastructure is currently a key research topic. It is focused on the exploration of flexible strategies to support the proper exchange of user data and in the identification of innovative technologies to use more efficiently the physical medium.

The first topic covers research questions related with the need of ensuring a low-latency, low-jitter and high-capacity technology to fulfill the bandwidth requirements and the huge bitrates required to connect the BBU pool with the RRHs [19]. The preferred way to implement it is by using existing dark fiber to establish a point-to-point link between the BBU pool site and the RRHs. Despite the advantage in terms of bandwidth and simplicity, the cost of dedicated fiber connections may not be feasible for many operators. Thus, fiber sharing techniques based on Wavelength Division Multiplexing (WDM) may be integrated to reduce fronthaul's total cost of ownership (TCO).

Another limitation of CRAN is related to the specific RAT's timing requirements, which through successive generations have becoming more strict. Normally, permissible fronthaul optical networks latency ranges from 100 µs up to 400 µs. Considering, for instance, a 250 µs round-trip time and taking into account a 5 µs/km fiber latency, a maximum distance of 25 km between BBUs and RRHs must be considered [13].

The first attempt to deploy the fronthaul infrastructure in C-RAN systems is based on the CPRI, which requires some sort of dedicated point-to-point link, leading to an inflexible and inefficient implementation. This has led to a new trend and current research topic on the adoption of packet switched networks to support the fronthaul [10]. The developed testbed is currently based on CPRI, but its modularity allows an easy and selective upgrade of the fronthaul interface (e.g. based on Ethernet or IP networks).

Last but not least, to use efficiently the fronthaul physical medium, the transport of I/Q between the BBU and the RRHs must be conveniently addressed. In the digitized radio signal, sampling rates are proportional to the channel bandwidth. For instance, considering a typical Macro Cell configuration for LTE 20 MHz, MIMO 2x2, 6 sectors and 16-bit I and Q samples, bitrates of around 12 Gbps are required (not including control and management channels). However, in LTE-Advanced, channel bandwidths of up to 100 MHz can be achieved (with Carrier Aggregation), which can lead to bitrates exceeding 60 Gbps. Thus, in this sense, novel strategies based on (de)compression mechanisms are increasingly

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