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CLOUD RADIO ACCESS NETWORK TECHNOLOGY FOR THE NEXT FIFTH GENERATION MOBILE NETWORKS

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ABSTRACT

Traditional mobile networks become unable to cope with the huge use of wireless internet services and the growth of data traffic. The solution to this challenges can be found in a novel mobile network architecture called Cloud Radio Access Network (C-RAN) that is expected to be the essential part of the next fifth generation of mobile networks (5G). The C-RAN system will achieve increased significant cost and address number of challenges for mobile operators in terms of optimization, configuration, network controllability and software management.

This paper will present and give an overview of C-RAN including system architecture and key techniques. It shows challenges and benefits of this technology. The paper presents also fronthhaul network requirements that must be achieved by the CPRI technology and transport options for C-RAN. User data plane, CPRI plane's control, plane's data Management and CPRI frame synchronization are also discussed.

Keywords: *C-RAN, 5G, CPRI, Fronthaul.*

1. INTRODUCTION

The fifth generation of mobile networks will be characterized by an increasing number of services, growing number of wireless devices and aggregate data traffic. Traditional base station (BS) architectures and coverage schemes have a lot of limitations such as limited capacity, insufficient expendability and low utilization and will not be able to satisfy all the challenges and requirements needed in next 5G mobile networks.

Furthermore, the new services and applications that will be supported by the future generations of mobile networks need to improve the user performance and satisfaction by taking advantage of user experience connectivity. To achieve this goal, The design and operation of the mobile network must take into consideration the QoE levels requirements for the different services.

The solution to these problems can be found in the new distributed architecture called Cloud Radio Access Network (C-RAN) that is new paradigm introduced by many organizations such as the Next Generation Mobile Networks (NGMN) project and the European Commission's Seventh Framework Programme to offer a new concepts in base station architecture [13] with higher intelligence.

Cloud Radio Access Networks (C-RANs) presents a promising solution to enhance and facilitate traditional radio transmission jobs and to communicate with core network. It is new technology that provide required Quality of Service (QoS) for the future 5G mobile networks, such as 10Gbps capacity, less than 1ms latency, and connectivity for numerous devices. It provides also a superior QoE.

The introduction of intelligence in the Cloud-RANs will also lead to satisfy complex context of operations and system requirements such as QoE (Quality of Experience) energy and cost efficiency.

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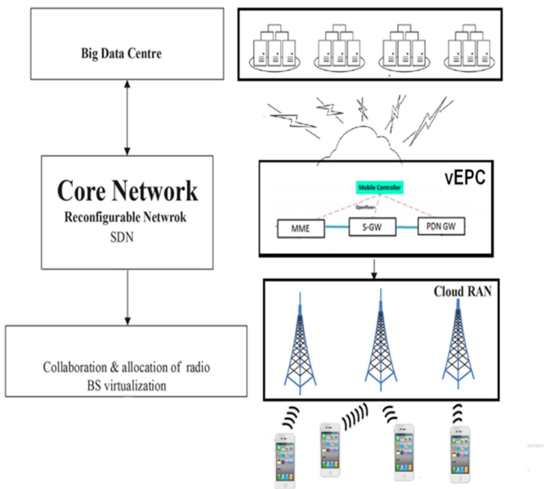

Figure 1. 5G mobile network architecture

While C-RANs offers several benefits and lower costs for mobile operators, a major update on the interface between C-RAN BSs and the core network (EPC) will be required in 5G network architecture to ensure interaction with high network operation efficiency. In addition, the two most important requirements for the deployment of the next 5G mobile network are flexibility and stability. The deployment of the new concepts and technologies must fit all uses cases and scenarios in order to optimize individual scenarios which require significant changes on the design of the 5G mobile network architecture.

The main innovative concept behind C-RAN is to pool the Baseband Units (BBUs) from several base stations into Centralized BBU Pool [16]. Radio signals will be exchanged between Remote Radio Heads (RRH) and the BBU Pool over Fronthaul transport network [R2]. The goal of decoupling the baseband processing from the radio units is to enhance redundancy and then maximizing operational reliability of the BBU pool. Despite this great advantage to efficiently centralize computational resources, C-RAN presents several requirements of next-generation mobile fronthaul architectures. In particular, Common Packet Radio Interface (CPRI) QoS requirements for the interconnection between the RRHs and BBUs [14][1].

This article is organized as follows: first, a literature review of C-RAN is given. (ou est section 2??) In Section 3, we introduce C-RAN systems for 5G mobile networks. Next, we give an overview of C-RAN architecture, roles of each network component and requirements to bring C-RAN concepts in 5G mobile networks. After, we describe CPRI interface fundamentals, optical CPRI transport options and requirements for C-RAN support in 5G.

In section 4, we demonstrate the motivation and driving forces behind the use of C-RAN in the next 5G mobile networks. In last section, we make conclusion.

2. RELATED WORKS

Nowadays, there is global discussion on the definition of the future C-RAN network architecture, its concepts and how can C-RAN boost network benefits and improve virtualization performance in the next 5G mobile networks. This discussion has conducted to many research works were recently published [2] [3][4][5]. In [2] paper, a new structure of C-RAN based on physical, control and service plane is given. Authors discuss in this paper the use and the benefits of the notion of service cloud, service-oriented resource scheduling and management for the proposed C-RAN architecture and how these technologies can facilitates the utilization of new communication and computer techniques. Cloud-based wireless network architecture for the next 5G mobile networks based on mobile cloud, cloud-based radio access network (Cloud RAN), reconfigurable network and big data center has proposed in [3]. Furthermore , authors of the [4] paper have outlined virtualization requirements and propose network architecture for Cloud-RAN base stations .They also present arguments for abstracting the EPC's view of the physical hardware connected to a C-RAN BS. In a [5] paper, Costa-Perez and al has discussed RAN sharing enhancements and benefits in the 3GPP RSE Study Item based on the use of several models. Related works on mobile carrier network virtualization were also provided by authors with a special focus on RAN sharing, base station programmability, and customization.

On the other hand and in order to improve the great potential of radio resources virtualization in reducing the overall capacity, a novel model to manage virtual resource has proposed in [6] .The proposed model is evaluated and tested in a practical set of scenarios and case study . The white paper [7] discusses the mobile operator's convergence and advantages of the use of cloud technologies in LTE network. Optical backhaul is the best solution providing capacity and transporting radio signals through C-RAN architecture. Towards this goal, several works was

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focus their efforts on evaluation and optimization of optical transmission that use WDM, OTN, PON and Ethernet technologies [8][9]. The authors of [8] evaluate the merits of a flexible backhaul by using different practical scenarios. They implement and design OFDMA-based C-RAN with reconfigurable backhaul architecture and show the potential performance and benefits addressed by this proposed architecture. They also create clear and effective vision of the need for configurable backhaul overlays for C-RAN. Furthermore, C-RAN architecture implementation example was given in [9]. Transport options for C-RAN support such us dedicated fiber, Optical Transport Network (OTN), Passive Optical Network (PON) and Wavelength-based systems were discussed . Benefits of Cloud-RAN Architecture in Mobile Network were also examined. [10] Describes the technical aspects of optical access solutions for mobile fronthaul application to achieve C-RAN architecture and data transport including the mentioned optical options given in [9]. In [11] an overview of optical fronthaul technologies, efficient and scalable solutions are presented, and finally an overlook into which 5G service requirements may further impact future backhaul, midhaul, and fronthaul networks was provided. Authors of the [12] paper provides an analysis and description of the key architectural challenges for the design of a flexible 5G transport infrastructure. Benefits of deploying flexible transport Networks using different case studies are given. Several optical approaches for transport networks design has also described. A detailed overview of C-RAN architecture needs, drivers of C-RAN technology and C-RAN deployment methodologies based on the mobile traffic requirements are presented in [13].

Some recent works have focused on specific aspect of the C-RAN transport infrastructure. A number of papers has defined the transport specification of fronthaul traffic through the description of the Common Public Radio Interface (CPRI) that is the most digital radio interface used for C-RAN transport over fiber. [35] Discuss the CPRI specification and requirements, coordination between cells in C-RAN architecture and options for CPRI transport are also presented. Authors show also the CPRI fronthaul benefits compared to Ethernet backhaul. Mugen Peng, Chonggang Wang, Vincent Lau, and H. Vincent Poor [14] gives an overview on the recent advances in fronthaul C-RANs including components and system architecture of C-RANs, options of C-RAN system structures, CPRI signal compression and quantization, and allocation and optimization (RRAO) techniques. In [15] paper, authors presents the CPRI specification, its concept, CPRI Frame and interfaces. The paper provides also a use case for LTE C-RAN environment and an overview of upcoming challenges for the future 5G mobile networks.

The [16] paper give an overview of C-RAN technology including state-of-the –art literature, advantages of C-RAN architecture, required hardware solutions scenarios, CPRI IQ compression schemes and solution, and virtualization concepts. The performance and enhancement of CoMP through C-RAN was discussed in many works [17][19][18].

In [17] paper, Xiaoyuan Lu, Yunxiang Xu, Kejun Zhao and Wen Yang propose a new cloud radio access network architecture based on RF signal-switching to solve limitations of CoMP technology. Furthermore, the paper introduces a new narrow-band parallel technique. Simulations and theoretical analysis presented shows that the proposed technique is more performant than the standard techniques.

In [19], Matsuo and al. give a description on CoMP technology and proposes a novel shared RRH network. Furthermore, they propose the connection of remote radio heads (RRHs) to multiple BSs at the edge of C-RAN coverage areas. Simulation results presented in this paper shows that the use of shared RRHs with CoMP can significantly improve the system performance compared with the conventional RRH systems. System level simulation is used in [18] to present initial views on the application of BBU+RRU based CoMP system to LTE-Advanced. Furthermore, results show that the CoMP joint processing can be seeing as one of the candidate techniques for LTE-Advanced systems to increase the cell average and cell edge user throughput.

The paper [20] Gives a novel vision on the design and operation of C-RANs based on QoE. In this paper, roles of each network element of C-RAN architecture are given. The authors propose several models to achieve QoE requirements in terms of network design and operation methodologies.

3. C-RAN ARCHITECTURE AND KEY CONCEPTS

3.1 C-RAN Architecture

Cloud radio access network (C-RAN) is an innovative architecture solution for the next 5G

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mobile networks based on Cloud computing paradigms and a novel technique called baseband pooling. In C-RAN architecture concepts, the base station will split into two units, a Baseband Unit (BBU) that will be based on specialized hardware platforms utilizing digital signal processors (DSPs)[MCC3-9] and will implement the MAC PHY and Antenna Array System (AAS) functionalities, and a Remote Radio Unit (RRU)[13] that will be composed within three modules, called ONU module, battery module and antenna module [R12] and that will provide high data rate for UEs with best coverage through transmitting radio frequency (RF) signals to the UEs. In addition, BBU and Baseband processing will be centralized and shared among sites in a virtualized BBU pool [16] that will be located in a Central Office (CO) to achieve centralized digital processing, processing management and optimize BBU utilization between base stations[8]. On the other hand, RRU will forward the baseband signals from UEs to the BBU pool for centralizing processing in the uplink [14]. Furthermore, Radio access units (RRU) will be connected through optical fiber links to a CO and will use the Optical Line Terminal (OLT) to forward data received from the CO to the RRUs [20] and also to send electric power to the RRUs. Finally, RRU obtains the digital signals through fiber from BBU, converts the digital signals to analog, amplifies the power, and sends the actual transmission [10].

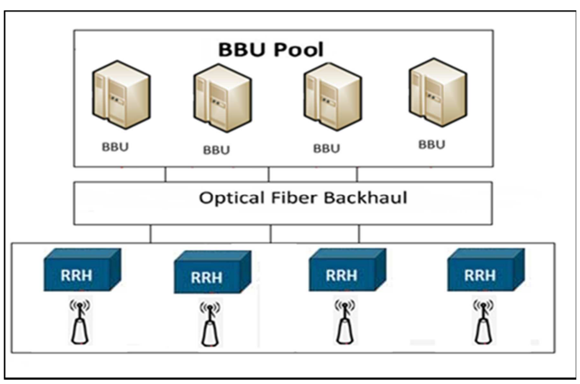

Figure.2. C-RAN Architecture

This centralization of all signal processing functions in the BBU will facilitate the use and deployment of cooperative technologies in 5G mobile networks such as Coordinated Multi-Point transmission/reception (CoMP) technology. Furthermore, BBU centralization can improve security without use of IPsec protocols.

There are various structures for the proposed C-RAN centralization presented as follows:

- Full centralization: In this structure, layer 1, layer 2 and layer 3 base station functions are located in BBU. This solution provide several benefits including :
  - Easier upgrading
  - Providing maximum resources sharing.
  - Support of multi-cell collaborative signal processing.
  - Support of multi-standard operation.

The most challenge of C-RAN with fully centralized deployment in the future 5G mobile networks will be the high bandwidth requirement between the BBU and RRH.

- Partial centralization: In this category, RRH integrates both radio and baseband functionalities (i.e. layer1 functions are incorporated in RRH).Higher layer functions are addressing with BBU.
- Hybrid centralization: It is seen as a very special case of full centralization. In this structure, partial functions in Layer 1 such as the user or cell signal processing functions are removed from BBUs, and assembled into a separate processing unit, which may be a part of the BBU pool. The benefit of this structure is the high flexibility of resources sharing and the high potential to reduce energy consumption in BBUs [14].

CPRI consists also of several topologies configurations to convey CPRI data over multiple hops. These topologies include chain, tree, ring and multi-hop options [34]

3.2 C-RAN Fronthaul Evolution Based On CPRI Interface

Common Public Radio Interface (CPRI) is the interface protocol mostly used for data transmission and interconnection between the RRHs and BBUs [21] .CPRI is a synchronous and full duplex protocol with transmit fiber and a receive fiber (CPRI provide its own synchronization without the need of GPS at the site). It is a digital interface standard, not packet-based and bidirectional protocol that define different types of QoS requirements such us capacity up to 10 Gb/s, transmission distance not less than 10 km and up to 40km, a jitter less than 65 ns, a near zero bit error rate less than 10e-12, and 3 ms as a maximum of delay excluding propagation delay [34].

There are also other types of protocols that can be used for this interface such as Base Station

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Architecture Initiative (OBSAI) [32] and Open Radio equipment Interface (ORI) [27], [28].

There are many technology options used to achieve CPRI transport. These technologies include the following optical solutions:

- Dark fiber: It is considered as the best solution for CPRI transport because the encapsulation of CPRI with another protocol introduces much jitter and latency. Another advantage of the use of the fiber is the introduction of O&M capabilities in CPRI. Dark fiber can also deploy with low cost without the need for additional optical network equipment. The most disadvantages of this solution are the high consumption of fiber resources and the need of protection mechanisms in the case of failure. Additional mechanisms are also required to implement Operations and Maintenance (O&M).
- Wavelength-division multiplexing (WDM): This solution is suitable for Macro cellular base station systems when there is limited fiber resource [C-RAN-whitepaper]. WDM introduce two best options for the CPRI transport .Coarse wavelength-Division (CWDM) and Dense wave Division Multiplexing (DWDM). CWDM supports low propagation delays and high data throughout. It is an economical choice, both in equipment's costs and in its use of fiber resources. In other hand and for larger aggregate transport requirements, dense WDM (DWDM) may be required.
- Optical Transport Network (OTN): OTN is introduced into the transmission layer in order to provide perfect OAM and support different topologies such as ring tree and mesh topologies [R14-20]. The use of OTN technology into CPRI transport requires careful consideration as a number of the highly valuable features of OTN. It introduces much latency.
- Passive Optical Network (PON): PON is a suitable option for CPRI transport in high-traffic areas. In PON approach, wireless base stations are co-located with optical line terminations (OLT) and optical network units (ONU). However, PON is vulnerable to additional latency and power loss, which further reduces the cell radius and makes fault isolation difficult. In fact, careful design engineering is required for PON to be competitive in cost. The future PON development have several directions like WDM-PON, Hybrid PON and 40G PON (Verification).
- CPRI over Ethernet (CoE): Due to its maturity and its adoption within access networks, the Ethernet implementation for transport in fronthhaul can offer many advantages and capabilities including operations, O&M capabilities and the support of performance monitoring of the network. It support the network managements protocols [R26]
  However, for addressing latency and jitter requirements, CPRI over Ethernet require additional equipment and Ethernet link between end points. These additional devices include commodity equipment and IP/Ethernet switches/routers to enable statistical multiplexing [9].
- Microwave: It is used for short distances (less than 1 km). A 2.5 Gbps CPRI link over microwave would typically reach about 500 m maximum. This solution is suitable for access areas were fiber is difficult to deploy and latency over microwave is very low. It can be used in campus or stadium.

In order to identify the optimal option, several parameters such as latency, cost and distance should be carefully evaluated and clearly defined . CPRI traffic must also take into account the aforementioned quality requirements to prevent distortion.

Optical fiber will be the ideal solution for C-RANs fronthaul because it achieves high transmission capacity and flexible deployment.

3.3 CPRI Protocol Layer Stack

As we can see from Fig.3, the protocol stack of CPRI interface consists of two layer called Logical and physical layer. The layer 1 covers physical and multiplexing functionalities and layer 2 provides capabilities for improved flexibility and scalability [31].

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The layer 1 is also responsible for detecting link failures, synchronization issues and line code violation .The Layer 2 capabilities provides access to several interfaces including :

- IQ data access
- Ethernet channel access
- Ethernet channel access
- High level data link control (HDLC) channel access
- Synchronization and timing access.

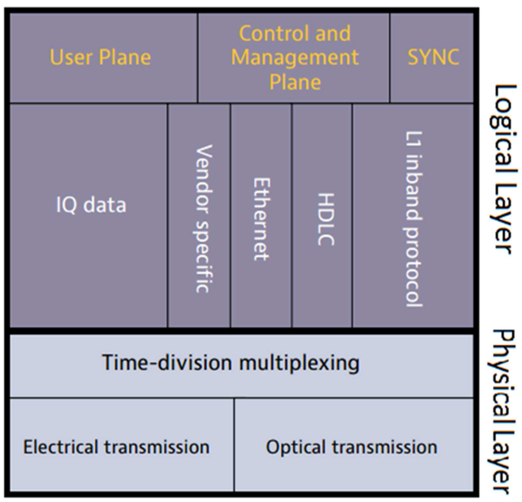

Figure .3.CPRI Protocol Layer Stack (CPRIv6)

A CPRI is typically segmented into three logical planes of operation[25][32]:

- User data plane: that is responsible for forwarding data to RRH over CPRI link in the form of In-Phase and Quadrature (IQ) data Block.
  In this plane, RE/RRH receive data, converts it into analog, amplifies and finally, the amplified data are radiated over the air to UEs.
- Control & management plane to achieve control signalling from remote radio and achieve operation, administration and maintenance of the CPRI link and the nodes. The two layer 2 protocols supported by Control & management plane are High level Data Link Control (HDLC) and Ethernet. Control and management plane can be transmitted by an inband protocol or by higher-layer protocols not included in CPRI specifications.
- Synchronization plane: transfer synchronizations and timing information between RRUs and BBUs. In this plane, synchronization signals are exchanged between the BBU us master and the RRH us slave. The central clock frequency generated in radio equipment RE/RRH must be synchronized with bit clock of the radio equipment controller REC/BBU.

CPRI supports transmission of IQ data between REC/BBU and RE/RRH in both directions. Furthermore, the flows of the different planes (User Plane data, Control and Management Plane data, and Synchronization Plane data) are multiplexed over the CPRI link through the CPRI frame.

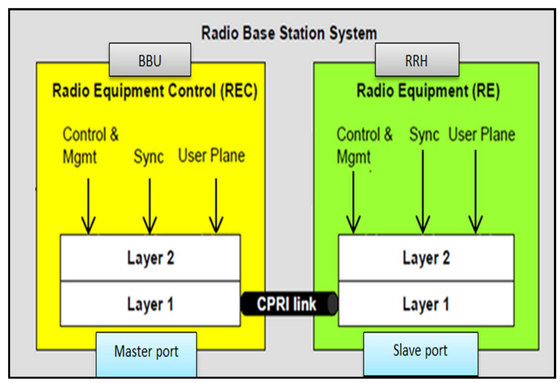

Figure.4. CPRI protocol planes

The CPRI protocol use multiple data blocks called antenna carriers (AxC).One AxC is the amount of digital baseband (IQ) needed for reception and transmission. Each IQ data flow represents the radio signal,

AxC contains one or more IQ samples for the duration of one chip (Tc = 1/fc = 260.416 ns since fc = 3.84 MHz)

The format for a CPRI frame is shown in Fig.5. CPRI sub channels are created per CPRI Hyper frame and 256 basic frames (260.42ns) compose the CPRI hyper frame (66, 67 us), A basic frame consists of 16 words with index W=0…15, the first word w = 0 is reserved for control, while the other 15 words are used to curry user plane IQ data. The length T of each word depends on the CPRI line bit rate. Here, 256 control words in one hyper frame collectively constitute 64 sub channels.

CPRI frame is a super frame formed by the collection of 150 hyper frames. Control & Management data and Synchronization information are mapped into the frame especially in the first word in every Basic frame (control word). This

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corresponds to the first Byte of Sub channel #0. [33]

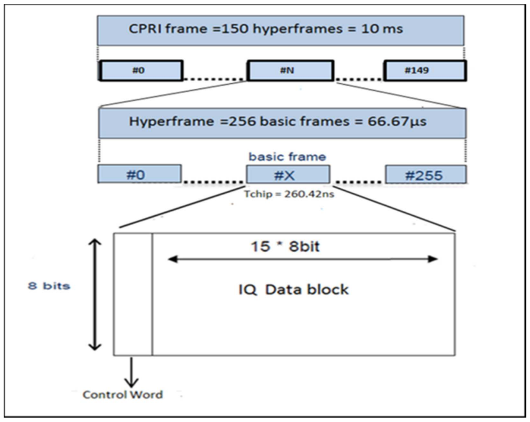

Figure 5.CPRI frame

3.4. IQ Compression

Data compression is the first step in packetisation of CPRI data. The goal of this approach is to reduce bandwidth requirements on the C-RAN fronthaul and optical transmission links that are caused by multi-band, broadband and increase of number of antennas.

The CPRI data compression solution should allow the C-RAN to meet the following requirements [35]:

- Achieved compression ratio should be a minimum of 50 % and should keep the signal quality.
- Signal quality (EVM) degradation caused by the compression/decompression should be less than 3%.
- Signal to noise ratio (SNR) degradation must be less than 1 dB.
- Processing time for compression/decompression must be less than 100 µs.

Various compression techniques were proposed in the literature. These schemes utilize the signal properties as well as varying network load [36] and are based on scalar quantization. Each of these scheme must satisfy the above conditions in addition to CPRI QoS requirements.

IQ data compression is an optional feature for the BBU and RRH, and operation of IQ data compression shall be negotiated between BBU and RRH via C&M Figure 6.

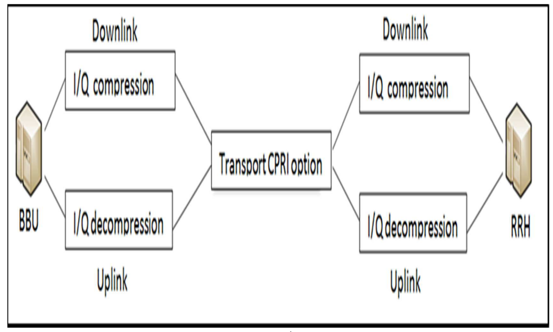

Figure 6. CPRI I/Q compression

The compression and decompression processing techniques should be added respectively inside BBU and RRU for the uplink and downlink transmission.

In the uplink (UL), each RRH compress its received signal and forwards the compressed data to the BBU through transport fronthaul link [14].

For downlink, in the BBU, the CPRI data generated by the BBU are compressed through compression module, then the compressed data are transfer through CPRI transport fronthaul link to RRU side. In the RRU, the compressed data are firstly decompressed through decompression module, and then convert the decompressed I/Q into analog radio signal that is transmitted [15]

4. C-RAN BENEFITS TOWARDS 5G MOBILE NETWORKS

Current trends in the development of the future 5G is to introduce C-RAN paradigm and concepts in the mobile network architecture in order to achieve and address the operator's challenges and open the door for new 5G applications and services. This motivation is driven by the benefits that can C-Ran offer to the 5G mobile networks. These benefits are presented as follows:

- Reducing cost and energy consumption of network operation: By placing base station and data information in cloud both power consumption and costs necessary to run network functionalities can be reduced.
- Offer high spectral efficiency: With C-RAN, Radio units could be more deployed and spectrum reuse will be enhanced.

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- Supporting multiple standards and the new evolution technologies: C-RAN can interconnect with several technologies, including GSM, UMTS, HSDPA, LTE and LTE-A [R14-12].The C-RAN entities can specifically manage and permit these technologies to communicate directly into C-RAN and to be managed by the same network.
- Provide a platform for additional revenue generating services.
- Improving network security: C-RAN offers the possibility of centralized encryption and ciphering which offer the opportunity to introduce new security algorithms and schemes and ensure security in a 5G mobile networks.
- Improving network controllability and visibility: C-RAN offer high level of visibility of the network devices which make easy their control and management.
- Improving network agility and flexibility: The centralized deployment of radio functionalities offers the opportunities for operators to manage the available resources dynamically and more efficiently.
- Dynamic adaptability to traffic fluctuations: with the utilization and adoption of sophisticated schemes and techniques, C-RAN can handle instantaneous fluctuations in the traffic.
- Improving network coverage and extension: to improve network coverage and increase capacity mobile operators should only implement new RRHs in C-RAN architecture and connect them to the centralized BBU pool.

- QoS support: C-RAN architecture supports multiple services for each user. These services require its own QoS metrics such as jitter, delay, packet losses and throughput. With the deployment of HQoS (Hierarchal QoS), C-RAN can achieve these QoS requirements and ensure the service availability [13].

- Reducing CAPEX and OPEX: Through the centralization of baseband processing. The Cloud RAN (Radio Access Network) can reduces cost, power consumption, and maintenance cost which implies reduction of both the CAPEX (-15%) and OPEX (-50%).

5. CONCLUSION

Next 5G mobile networks will be characterized by higher mobile data traffic, higher mobile subscriptions and more services. This implies operators to use high management architecture and to implement a new robust approach, based on best practices.

In order to accomplish those goals, C –RAN mobile network architecture has been proposed to be the principal part of the next 5G mobile communication networks.

The integration of C-RAN and its key concepts in the next 5G mobile networks will introduce intelligence, facilitate network topology design and will also provide good opportunity for operators to reduce both capital expenditure (CAPEX) and operational expenditure (OPEX) while still guaranteeing a good service.

This paper has outlined and surveyed the C-RAN architecture design, key techniques, C-RAN fronthaul requirements and options, and future considerations of C-RAN deployment in the next 5G mobile networks.

In our future considerations of C-RAN, more challenges, technologies and models of C-RAN will be discussed .C-RAN integration in the future 5g mobile networks will be also evaluated with simulations scenarios and use case .

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