Implementation of Cloud-RAN in 5G Mobile Networks

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Abstract **A C-RAN system which makes baseband processing resources as a pool centralized and on demand it virtualizes soft base-band units. With an proposed potential solutions the challenges in C-RAN i.e., front-haul and virtualization are analyzed. A test bed with assisted accelerators is established which can support multi-RAT including Time-Division Duplexing Long Term Evolution, Frequency-Division Duplexing Long Term Evolution and Global System for Mobile Communications, joint resource allocation, mobility management, as well as traffic steering and service mapping. In future mobile networks to meet the demand (C-RAN) have gained the priority also which reduces the capital and operating expenditure burden faced by operators. For an 5G system it requires a scenario, the ultra dense network deployment based on C-RAN is discussed with focuses on flexible backhauling, automated network organization, and advanced mobility management.**

Keyword - Components; C-RAN, multi - RATs, front-haul, virtualization

I. INTRODUCTION

As technology grows on telecom industry has been witnessing a traffic explosion in recent years. It has been estimated that consumer Internet traffic is expected to increase over 1000 times by the year 2020 with over 50% of the traffic volume in file sharing. Because of this tremendous growth operators have to invest in more infrastructures, significantly increasing total costs. This not only increases total cost of ownership (TCO) but also complicates maintenance with several networks such as 2G, 3G and 4G co-existing with each other. And also system upgrades become more challenging when new technologies like 5G are introduced into the multi network environment [1].

Second, comparatively intrusion problems in current LTE (Long Term Evolution) networks are much more severe than in 2G and 3G networks due to a larger number of small-cells in order to facilitate higher data capacity which provides storage. In order to lessen this intrusion, collaborative radio techniques such as Coordinated Multi-Point (CoMP) have been proposed. Power consumption is another concern for operators as both the carbon footprint and energy costs of the network increase. Large percentage of power consumption in mobile networks comes from radio access networks (RAN). As a result, saving energy in the network's RAN directly lowers the OPEX of the network.

A. Motivations for 5G Mobile Networks

Main reasons or motivations for the development of 5G mobile networks are., Firstly, a network service which provides shorter setup time and less delay as well as reduced signaling and energy consumption [3] e.g., massive sensor communication and vehicular to anything communication [2]. Secondly, to maintain optimal performance in future cellular systems by more flexible resource usage and more advanced self-organization functions operators expect to reduce networks operational costs and improve spectral efficiency within an area.

With the popularity of the Internet of Things, the machine type communications over mobile Internet raise more demands to network performance, such as low-delay and high-automation. These requirements will go beyond the natural evolution of IMT-Advanced technologies, which shows the need for a new mobile generation, e.g. 5G technologies.

Multiple organizations from many countries have started their activities towards the definition of 5G. Among those METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) aims at laying foundation for the beyond 2020 wireless communication systems by providing the technical enablers needed to address the very challenging requirements.

Before coming to 5G network traditional RAN architecture has several challenges in the 4G and beyond. First, traditional network distribution usually requires a base station(BS) base band unit(BBU) to be accommodated in separate room with supporting facilities.

B. Concepts and Technologies for 5G Network

The relations among C-RAN, NFV and SDN gives the details about how C-RAN integrates the other two technologies to realize multiple levels centralized management in BBU pool.

C-RAN is a centralized, cloud computing based new cellular network architecture which has the ability to support current and future wireless communication standards. C-RAN provides several advantages such as scalability and flexibility of further deployment of plenty of remote radio heads (RRHs), compared to the conventional RANs.

NFV (Network Function Virtualization) refers to the implementation of network functions in software running on general purpose computing/storage platforms [4]. This approach allows the deployment of network functions in data centers to leverage the traffic load through virtualization techniques.

SDN (Software defined Network) is an emerging architecture that decouples the network control and forwarding functions, enables the network control to become directly programmable and the underlying infrastructure to be abstracted to adjust applications and network services dynamically.

These three concepts relate to each other, but contribute for different domain. SDN is focused on the separation of the network control layer from its forwarding layer, while NFV is focused on implementing network functions in software on standard IT platforms. In case of RANs, when NFV is used for logically centralizing the base band processing within the RAN, C-RAN becomes an application of NFV. Three forms of virtualization in a C-RAN solution can be potentially co-existed on a cloud BBU pool, based on General Processing Processor (GPP) platform: hardware virtualization, network virtualization and application virtualization.

-In hardware virtualization, a portion of the RAN hardware is virtualized, i.e., a virtual RAN layer, is created and managed by a hypervisor which is used for same work.

-In network virtualization, where switches, routers, edge caching storage elements and transport resources are the network elements which are abstracted and combined into a pool that is managed by a network operating system.

-Application virtualization presents within the RAN, where a virtualization layer replaces the network management application entities which allows existing applications to run in the C-RAN without the need to rewrite the software.

II. OVERVIEW OF C-RAN

A. C-RAN Architecture

C-RAN stands for Centralized, Collaborative, Cloud and Clean RAN is a new type of RAN architecture to help operators address the aforementioned challenges. Through C-RAN different baseband processing resources are centralized to form a single resource pool such that the resource can be managed and dynamically allocated on demand. C-RAN has several advantages over traditional base-station architecture, such as more utilization of resources, less energy consumption and decreased interference (better support for CoMP implementation).

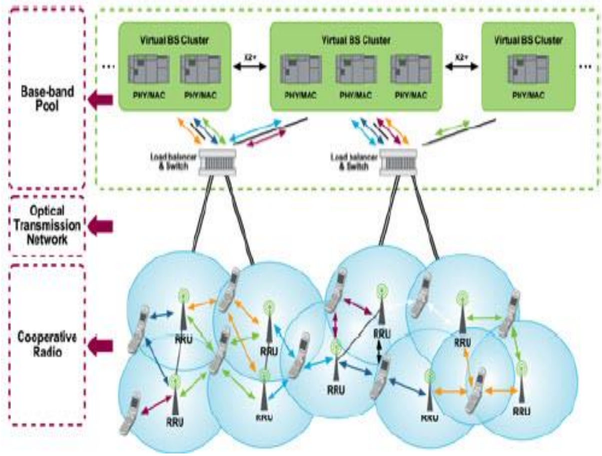

Figure.1. C-RAN Architecture

C-RAN mainly comprises of three components, namely (i) BBU pool with centralized processors, (ii) RRHs (**remote radio head)** provided with antennas located at the remote sites, (iii) fronthaul network requires high bandwidth and low-latency which connects the RRHs to the BBU pool.

The RRHs transmit the RF (radio frequency) signals to UEs in the downlink or forward the baseband signals from UEs to the BBU pool for further processing in the uplink. In general, the RRHs include RF amplification, up/down conversion, filtering, A/D and D/A conversion and interface adaptation.

The BBU pool consists of several BBUs within it which operate as virtual base stations. These base stations are used to process baseband signals and optimize the network resource allocation. Considering different demands on network performance and system implement complexity, the BBU assignment for each RRH could be implemented in a centralized or distributed manner depending on different resource management in BBU pool. In C-RAN architecture RRH will be present in a distributed manner, one RRH directly connects to its exclusive BBU. This manner is simple and easy to be realized. But it is not beneficial to exploit the advantages of joint signal processing and central controlling in C-RAN. In the centralized manner, all RRHs may connect to a switcher/central device, which can flexibly schedule processing resource in BBU pool for one RRH or a set of RRHs. This manner features many advantages in term of flexibly resource sharing and efficient energy efficiency by joint scheduling.

The fronthaul links can be realized by using different technologies, like fiber or wireless, and falls into two categories: ideal without bandwidth constrain and non-ideal. Optical fiber is always seen as a way of ideal fronthaul for C-RAN, because it can provide large bandwidth and high data rate. For instance, the NG-PON2 has the following performance specifications: bandwidth of 40 GHz and 10 Gbps for the downstream and upstream respectively, and range up to 40 km. Wireless backhauls is faster and cheaper to deploy than fiber. Traditional wireless backhaul generally operates on the licensed band by reuse techniques such as relay. Wireless backhaul can also employ the microwave technology with carrier frequencies between 5 and 40GHz. However, due to the limited available bandwidth at these frequencies, they can provide data rates of only a few hundred Mbps. A transport network provides a connection between a BBU instance in a pool and the RRU. It could be of different forms depending on the scenario. Some examples include direct fiber connection via dark fiber, microwave transmission and fiber transport networks.

B. Related work

Some operators in China already start the C-RAN network deployment. And several service providers and equipment manufacturers also have developed the prototype system, e.g., Light Radio from Alcatel Lucent [5], Antenna-integrated Radio (AIR) from Ericsson [6], FluidNet from NEC [7] and CloudIQ Framework proposed by several corporations [8]. C-RAN projects have been initiated in many organizations such as Next Generation Mobile Networks (NGMN), European Commission's Seventh Framework Programmed (EU 7FP), etc. C-RAN projects, this work stream aims at further detailed study on key technologies critical to C-RAN implementation, including BBU pooling, RAN sharing, function split between the BBU and the RRU, and C-RAN virtualization.

There are several C-RAN related projects under EU FP7. For example, the iJOIN project deals with the interworking and joint design of an open access and backhaul network architecture for small cells on cloud networks [4]. Another project, Mobile Cloud Networking (MCN) aims at exploiting Cloud Computing as infrastructure for future mobile network deployment, operation and innovative value-added services. C-RAN is not only applicable for existing wireless networks but also an essential element for future 5G systems [1]. C-RAN is supposed to be able to accommodate and facilitate several 5G technologies such as Large Scale Antenna Systems (LSAS), full duplex, ultra-dense networks and so on, mainly thanks to its inherent centralization nature as well as the flexibility and scalability of a cloud-based implementation [3].

FRONTHAUL ISSUES

C-RAN has attracted many academic research interests. Through the ability of centralized processing/controlling/decision in C-RAN, the joint processing becomes relatively easy, including CoMP defined in 3GPP Release 10, joint scheduling, joint interference alignment/cancellation and other more advanced future technologies, such as multi-RAT support, common Operation and Maintenance, reliability and network sharing, which are difficult to be implemented in current cellular networks [12], [13].

Some joint processing techniques envisioned for such cloud-based networks require RRH to deliver received signals to BBU pool, usually in the form of in-phase and quadrature-phase components (I/Q-stream), which demand a drastically higher data rate on the fronthaul link than decoded user data [14]. Until recently, the required data rate could only be provided by fiber and not by wireless links, which could be reached more easily and at lower cost in C-RAN architecture [15]. There are two kinds of efforts having been done to solve the problem: one is to reducing the throughput requirement on transportation links by means of joint coding under a data rate constraint, or resampling, rescaling and removing some unnecessary parts of the signal, the other is developing enhanced fronthaul technology that supports wideband and high data rate, such as millimeter radio links.

FEATURES AND ADVANTAGEOUS OF C-RAN

C-RAN appears to nothing more than the centralization of BBUs, centralization is just the first step towards a complete C-RAN:

- BBU Centralization: This is the most basic feature of C-RAN.
- Advanced Technology Facilitation: C-RAN is an inter-connection switching network of high bandwidth and low latency. This switching mechanism realizes interconnections of different computation nodes and enables efficient information exchanges among them. As a result, many technologies that are difficult to implement in traditional architectures, especially joint processing and cooperative radio, will become viable in a C -RAN context. In this way, the system performance can be improved greatly.
- Resource Virtualization/Cloudification: Unlike traditional RAN systems in which computation resources are limited within one BBU and therefore cannot be shared with other nodes, in C-RAN these resources are aggregated on a pool level and can be flexibly allocated on demand. This feature, similar to the cloud and virtualization concept in data centers, is called resource “cloudification”. It will improve not only resource utilization efficiency but also power consumption.
- ”Soft” BBU: Traditional wireless equipment are developed based on proprietary platforms and possess only “hard"” fixed capabilities designed for carrying peak traffic. While in C-RAN BBU pool, through resource cloudification, a BBU is of soft form, which means that the capability of a soft BBU could be dynamically reconfigured and adjusted. In this way, resource utilization efficiency can be greatly increased.
- Facilitation of service deployment on the edge: a C-RAN network covers a larger area and serves more users than traditional single base station. Making use of this, it is possible to move services to or directly deploy new services on the RAN side. In this way, the user experience could be improved and backhaul pressure could be relieved.

III. C-RAN IMPLEMENTATION IN 5G NETWORKS

A. Fiber Resource Challenge by Centralization

front-haul is defined as the link between BBUs and RRUs. Examples of front-haul protocol include Common Public Radio Interface (CPRI) [16] and Open Base Station Architecture Initiative (OBSAI).

Centralization is the critical first step required in order to realize all the other features of C-RAN. Centralization aggregates different BBUs (typically several dozens or several hundred carriers) into one central office with shared facilities. The key challenge for centralization is that it requires a large number of fiber resources if using a dark fiber solution, i.e. direct fiber connection. The issue can be illustrated by the following example. In a TD-LTE system with 20MHz band-width and RRUs equipped with 8 antennas (most common scenario in the CMCC network), the CPRI data rate between one BBU and one RRU for one TD-LTE carrier transmission is as high as 9.8Gbps. When considering both UL and DL, 4 fiber connections would be required with 6Gbps optical modules. Since usually one site consists of three sectors with each supporting at least one carrier, the number of fiber connections for one site is as high as 12, which is difficult to achieve for most operators due to limited fiber resources.

In order to overcome the fiber disadvantage in a centralization implementation, various solutions have been proposed. Some are mature enough while others are still in the early stage of development. Compression techniques are the first steps taken to reduce fiber consumption. There are various kinds of compression techniques such as non-linear quantization and IQ data compression with a lossless 2:1 compression ratio [17]. Another solution is Single Fiber Bi-direction (SFBD) which allows simultaneous transmission of UL and DL on the same fiber. SFBD could further reduce the usage of fiber by another 50%. As a result, when combining SFBD with compression, fiber resources can be reduced 4-fold with lossless performance. Another method to reduce fiber consumption is to introduce new transport nodes for front-haul transmission.

B. Application of Cloud Computing and Virtualization

C-RANs core feature is resource cloudification in which processing resources can be dynamically allocated to form a soft BBU entity. Given current vendors' proprietary and closed platforms, it is advantageous to develop a new BBU platform based on virtualization technology found in modern data centers. One suitable method of network virtualization is to use network function virtualization (NFV) which "consolidate{s} many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Data centers, network nodes and in the end user premises"[18].

C. Challenges of C -RAN Under UDN Deployment

Small cell deployment is one of the most promising technological trends to cope with the rising need for very high data rates foreseen in future mobile networks which involve various types of small cells such as picocell, relay, Machine-to-Machine, and also Device-to-Device [19].

Because of the densification of small cells, the distance between UE and access point is greatly reduced, i.e. tens of meters, therefore one UE will fall into several small cell coverages, and all of those small cell BSs can receive the UL signal from the UE or serve the UE in downlink. Based on this property of UDN, some joint/collaboration mechanisms can provide better experience of users.

Frequent handover will occur under UDN, which will bring high burden to the signaling overhead and harm user experience. Besides, handover failure and ping-pong issues may also appear by reduced small cell size and larger inter-cell interference. For LTE X2-based inter-eNB handover, C-RAN could reduce the handover delay and to a large extent eliminate the risk of UE losing its connection with the serving cell while still waiting for the handover command, which in turn decreases the handover failure rate.

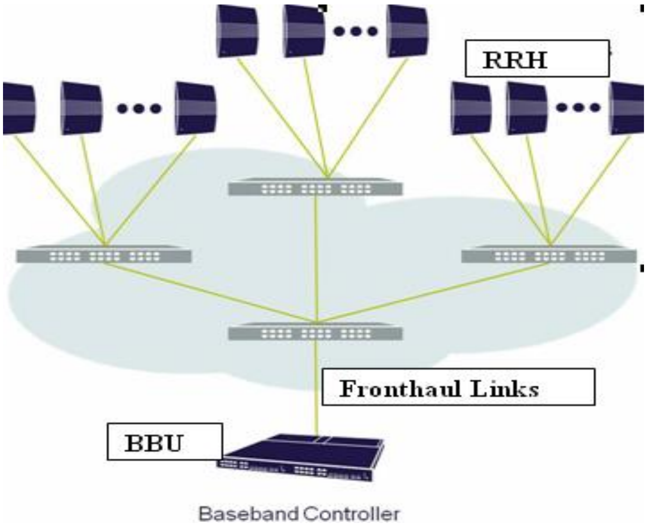

Figure.2. C-RAN architecture under UDN deployment

Under UDN deployment, there is a discernible phenomenon that traffic load varies from time to time. In C-RAN architecture, the BBU pool can evaluate the current situation of whole network in terms of traffic demand, system performance level, target system performance level, criticality of user, energy status at the time of day and many other similar factors to decide whether the activation of the respective small cell RRH is needed or not. For example, if a certain part of the macro cell contains a large number of UEs and the rest of the cell area has a low number of users with low traffic demand requests, the BBU pool can offload the users in the congested area by activating the respective RRHs and handle the rest of the users by macro RRH.

D. Integrated Multi-RAT Operation in C-RAN

As mentioned above, UDN is a step further towards low cost, self-configuring and self-optimizing networks [20]. In addition, 5G system will need to deal with many more base stations, deployed dynamically in a heterogeneous manner and consisted of multi-Rats, like GSM, UMTS, LTE, Wireless Fidelity (Wi-Fi), etc., which need to be flexibly integrated. Current wireless communications systems are deployed using multiple RATs both in licensed and unlicensed bands, and the operations of different RATs are independently defined by their specific standards. However, independent RAT operation leads to suboptimal usage of the wireless resources. Multi-RAT joint radio operation is therefore necessary to improve the system resource usage.

1) JOINT RESOURCE ALLOCATION

As aforementioned, multi-RATs, operating with different system configurations and resources, have evolved and will coexist for a long time to meet the heterogeneous demands for the network and mobile UEs with different capabilities. The fixed spectrum allocation in current wireless network has seriously restricted the spectrum efficiency, and affected the development of wireless networks because of the spectrum sparse and imbalanced load distribution among different RATs. RRH on/off flexible configuration is easy to implement across multiple RATs in the whole network. Dual-connection, virtual MIMO, joint beam forming, are effective approaches to improve network capacity specified by 3GPP. To support these joint processing technologies, network should configure UEs to measure channel statues and exchange the measurements among the set of collaborative nodes, which brings a lot of signaling overhead.

2) MOBILITY MANAGEMENT

Currently, LTE is designed to support inter-RAT handover for GSM, UMTS, and now specified to support interworking with WLAN. Through sinking data forwarding, user plane to BBU pool and integrating approximation function modules of 2G, 3G and LTE network, the inter-RAT handover process is simplified and the distance between traffic anchor and interface is shortened, which reduce the handover time.

3) TRAFFIC STEERING AND SERVICE MAPPING

Additionally, the notion of intelligence is being exploited so as to guarantee the ubiquitous and reliable user experience and improve performance of Multi-RAT integrated deployments by taking advantage of global information about users, services and network status.

Intelligence shall then lead to decisions related to: 1) the cell configuration and resource allocation,

and the traffic distribution to the cells; 2) the assignment of functional components to the computing resources; and 3) the best connections between RRH and BBU pool and the best interconnections between the multi-RAT operations.

Various users have diverse mobility and service properties, realized by different process inside the wireless system, such as Intelligent Copying System without mobility and real-time traffic demand, whose traffic can be assigned in night when wireless traffic load is low. Besides, no mobility related policies are expected to be launched for this class user.

IV. CONCLUSION

In this paper, we present an overview of C-RAN architecture and simple BBU stacking to resource cloudification, C-RAN can be advantageous to both operators and customers by reducing power and energy consumption and improving spectral efficiency. In the complete overview of C-RAN it includes major two challenges: centralization with efficient front-haul solutions and virtualization implementation to realize resource cloudification.

Also C-RAN is having several hot issues especially in UDN and Multi-RAT coordination. With the combination of NFV and SDN, for various RANs C-RAN can define a unified interface, and integrate their processing resources (even spectrum resource) into the whole BBU pool. Moreover, placing data plane in RAN facilitates C-RAN to perform advanced traffic steering and mobility management based on user perception and mobility prediction in Multi-RAT coexisted networks. Although the benefits of C-RAN are clear and reasonable, the implement in practical networks still need in-depth research, considering practical constrains of the heterogeneous fronthaul links.

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