Optimization in Fronthaul and Backhaul Network for Cloud RAN (C-RAN): Design and Deployment Challenges

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Abstract: **Cloud Radio Access Network (C-RAN) is consider to be most promising technology for the next generation mobile and wireless communication. C-RAN split the different functionalities of the traditional base station (BTS) in to simplified Base Band Unit (BBU) and Remote Radio Head (RRH) unit. The efficiency and throughput of the C-RAN system is depend on the fronthaul and backhaul link capabilities, at present scenario network link bandwidth is not scalable to accommodate the large growing traffic and required more modification in the network link structure. In this paper, we give an overview of the main challenges of the current fronthaul and backhaul network, and discuss about different possible network configuration for C-RAN .As the transmission capabilities of a network link depend on the bandwidth of the transmission medium, optical network along with WDM technology consider to be best option for C-RAN. The advance optical modulation technique, hybrid transmission technology along with the fault tolerance mechanism are discuss and compared interm of their performance and capabilities.**

Keywords—C-RAN,Fronhaul,Backhaul,WDM,Optical link,Microwave link

I. INTRODUCTION

The continuous exponential growth of Smartphone users and intelligent device results increase in network traffic, which require greater channel bandwidth at RF or physical channel, which have the capabilities to aggregate all the incoming RF signal and send them to other base station or switching station. The study given by Cisco [1] Show that the global IP traffic growth around one zettabyte [1000 byte] per year at the end of 2016,and it is expected to be increase two zettabyte at the end of 2019.Which again show that around 70 % of the total IP traffic should be non-pc based, till the end of the 2020 against the 40% at present scenario, this all the expectation is because of increase in smart phone user M2M, IoT, Intelligent Devices and V2V communication for smart traffic. In india the smart phone user has been increase four time against 2010, along with that 3G data user is increase three time.

To accommodate this large data traffic which is increasing day by day in the cellular network different technology has been evolved like small cell, SON, Cognitive Radio, SDN and C-RAN etc. Cloud RAN is the new concept develops by china mobile in 2011, and has been successfully implemented in some part of the china and south Korea. There are around 20 to 30 company are working on either service level and design level around the globe by focusing on the different issues related to C-RAN. Company like Orange mobile, China Mobile and Telefonica are working at service level ,where as Alcatel-Lucent, Nokia-Siemens and LightRadio are mainly working on the design and development of C-RAN, along with that many academic Institution and research organization like Tsinghua University ,University of Luxembourg, China mobile research Institute, IIT Hydrabad , Bell lab, Erricsson development center etc are also join hand with the cellular company for development of this new architecture. So in the present scenario C-RAN consider to be the next big thing after the Cognitive Radio in the cellular network. In term of capital cost (CAPEX) , operational cost and energy efficiency C-RAN consider to be the best alternative for small cell design challenges .The main objective of the C-RAN is to reduce the density of the traditional base station in highly dense populated region like metropolitan cities like Mumbai and Delhi of India,where the cellular traffic density is very high and it is growing rapidly,so every time it is very difficult to added new base station, so flexible and scalable network is the main concern in the new generation cellular network to accommodate drastically increasing mobile traffic and to provide very high data rate. The traditional base station consist of a antenna unit and baseband processing unit collocated at same geographical location and connected through a thick lossy RF coaxial cable [2,3]. In C-RAN some the functional unit is separated from the base band unit and place near to the antenna and known as remote radio unit (RRU) and processing unit know as base band unit (BBU). All the BBU unit is co-located centrally at of distance of around 2-40km from RRU. The interlink between BBU and RRH unit perform by fronthaul network. The most common fronthaul network consist of lossless optical fiber cable (OFC), Dark fiber or wireless microwave link [4]. The digital base band data are carried out through the optical fiber using the OBSAI or CPRI standard. Although the optical fronthaul is most common fronthaul network, the current development in the wireless technologies give a new direction to service providers to use wireless fronthaul as an alternative backbone in the C-RAN.

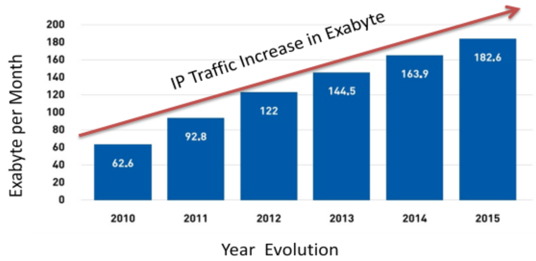

Figure.1 Global IP traffic from 2010-2015 [Source: Cisco-VNI mobile]

The additional characteristic like resource virtualization, centralized processing included more facility to the C-RAN architecture and develops on the base of an IT platform. The practical implementation of the C-RAN comprised two constrain i.e spectral efficiency (SE) and the second one is the energy efficiency (EE). Based on this estimation the fronthaul and backhaul network will be design [5,6].

II. DIFFERENT ISSUES WITH CURRENT FRONTHAUL AND BACKHAUL TECH-NOLOGY:

In traditional distributed RAN (D-RAN) configuration the received signal by BBU is amplified, filtered and processed by the signal processor , then through switches its passes to the antenna unit for retransmission to the end user. In the D-RAN architecture the Base Station is connected to the long distance main switching centre (MSC) by either optical backbone or dedicated microwave link. The main limitation of the D-RAN architecture is that it's required a high capital cost (CAPEX) and operational cost (OPEX), again the call handling latency incurs in the D-RAN is very high because the total call forwarding and call switching is done at only remote MSC, due to the use of co-axial cable and distributed power amplifier the throughput of D-RAN architecture is only 10-15% of the total power consumption. This limitation of the D-RAN force the mobile service provider and manufacturer to redesigned the RAN baseband and interconnect network architecture. C-RAN is the next alternative to reduce all the limitation and provide a better quality of service to the end user interm of throughput, datarate, and latency. As the cellular traffic increase to accommodate this backhaul as well as front haul should be more densified .This network densification can causes many fault and problem in the physical network. In [7] suggest two alternative solution to handle the network densification and fault tolerance first one is cloud based scalable centralized BBU and wireless based fronthaul and back-haul network. In paper [4,8,9] mention different optical network and optical modulation technique like WDM,C-WDM,DWDM and network like IWDM-PON network CWDM-OCM. The present scenario of mobile communication like 3G and 4G take the advantage of optical multiplexing and use the technique like optical frequency-domain-multiplexed (OFDM) for LTE and LTE-A signals. This signals used either analogue or digital signal processing or direct modulation of multiple IF over the fiber (IFoF) technique, but the radio-over-fiber (RoF) techniques reduce the complexity of radio unit but largely suffer from linear and nonlinear distortions (NLD) due to different light sources like Laser diode or Super luminance diode. Chromatic dispersion is another parameter which increase nonlinearity in fiber, this parameter in fiber cable increase latency and causes more optical interference in fiber cable, so compensation of this NLD and dispersion minimization is the key challenges during the installation and selection of the optical fiber as fronthaul or backhaul network for next generation cellular communication [10,11] .

In this paper the first section describe about different fronthaul and backhaul network, and categories them in term of configuration of frounthaul-backhaul and discuss its aspect over the C-RAN network, the second section we have described the different optical configuration technique and fault tolerance mechanism for optical network [12].

1. Fronthaul-Backhaul Network Configuration for C-RAN:

Fronthaul network is the network which provides connection between RRH and BBU, where as the backhaul connects the C-BBU and main switching center (MSC). Based on the parameter like data rate, bandwidth, traffic load , geographical feasibility and cost incur for the fronthaul and backhaul installation, all fronthaul and backhaul installation for a cloud

RAN system can be categorized into four different configurations, (A) Wireless-Wireless network (B) Wireless-Ethernet (C) Wireless–Optical network (D) Optical–Optical network.

A. All Wireless network (Wireless -Wireless) :

From many alternative connections between RRH-BBU connection in C-RAN , wireless source like microwave can be used as fronthaul as well as backhaul in different environmental condition such as market site ,road site ,railway site ,densely packed localized area,harsh environment like hilly unreached area , industrial area and for temporary mobile cell site, wireless Company like E-Blink, Ericsson and Nokia provide wireless infrastructure for enabling the wireless fronthaul network for C-RAN architecture. The Ericsson and E-Blink have developed a microwave fronthaul unit (MFU) for all outdoor setup,each MFU unit is having best spectral efficiency and capabilities to work on multi-frequency band with a low line rate cost.

The standard MFU generally working on E-Band (70/80GHz),line rate 2.5-10 Gbps CPRI up to 1km and bandwidth 30-500 MHz . The long distance and high capacity wireless backhaul should be high enough to accommodate a large number of the channel simultaneously to get a higher throughput and minimum latency.

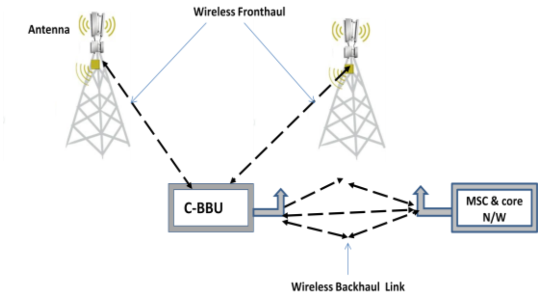

Figure.2. Wireless-Wireless Fronthaul-Backhaul C-RAN Architecture

The two options for the wireless backhaul first one is daisy chain for long distance microwave link with the help of the directional antenna, the second option is the use of satellite link by the use of a transponder to handle a large number of simultaneous wireless channel. Ceragon has develop a complete microwave backhaul solution known as ultra-high capacity wireless backhaul (UHWB) which work on E and V-Band of microwave link with a higher channel band gap 112 MHz and 224 MHz, Again Ericsson has suggested five microwave band XL,L,M,XS,S for different geographical area as mention in table.1.[13]. This type of RAN configuration is best suitable for co-operative small cell communication where the service provider is best known for the channel capacity and resource bandwidth. This wireless backhaul can be integrated with the optical backhaul as a hybrid backhaul network for fault tolerance and efficient resources utilization. The limitation of this configuration is that it has a very less channel handling capacity due to limited bandwidth , also this is more sensitive to noise and interference as compared to its wire based counterpart. The main challenge in this configuration is that as both the front and backhaul network working on same microwave frequency range signal interference held between these two signals, which caused signal degradation and limit the efficiency of the system, again atmospheric attenuation limit the microwave signal to a few kilometres. To overcome this type of limitation more research are going on to implement a full-fledged adaptive wireless backhaul to avoid the high-cost optical installation.

Table.1 Different microwave band and its spectrum, which can be used as Fronthaul and Backhaul wireless link [Source: Ericssion]

Range in GHz	Spectrum In GHz	Microwave Band	Area of Use
6-13	5	XL	Rural
15-23	5	L	Suburban
26-42	13	M	Urban
60	9	XS	Urban
70/80	10	S	Urban

B. Wireless – Ethernet Network:

In this configuration, the fronthaul network should be considered as the microwave of different frequency band which links between RRH and BBU unit.The backhaul should be a high capacity, low loss coaxial cable, digital subscriber line (DSL) is another option, where a copper cable is used to transmit a large amount of data with higher data rate. Hybrid fiber coaxial cable (HFC) is another configuration where all the RRH node connected to the main node coaxial node and then to the nearby Main switching center (MSC) having optical node, then its transmit through the optical trunk link to other MSC [14,15].

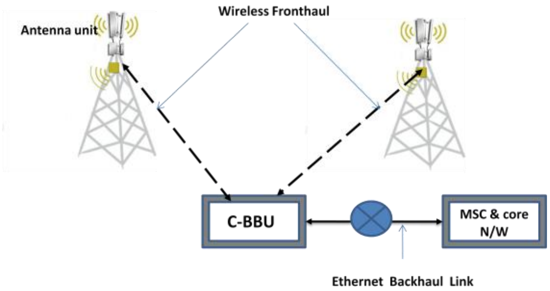

Figure.3. Wireless-Ethernet Fronthaul-Backhaul C-RAN Architecture

As this architecture is very robust and easy handling, but there are many drawbacks like high capital and installation cost, low data rate and low throughputs still exist with the system. Due to the high cost, greater latency , low channel bandwidth and greater transmission loss this RAN architecture is not widely acceptable for the cloud-RAN architecture.

C. Wireless-Optical Network:

This is a widely accepted configuration, where the fronthaul connection is wireless i.e. microwave link, but the core network or backhaul network is optical fiber. This RAN architecture is most widely used for small cell wireless network, where all small cell are wirelessly connected to the centralized small cell BBU which is a macro-BBU , then this is connected to central office by optical fiber cable, As the small cell can be install in any public utility place like light pool, rooftop and tree trunk etc, they can easily accessible to the micro base station and then to the central office [6,17].

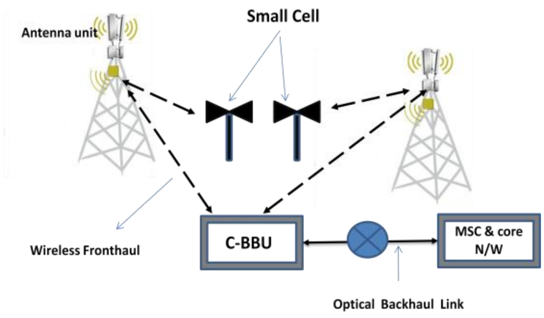

Figure.4. Wireless-optical Fronthaul-Backhaul C-RAN Architecture

D. All Optical Network (Optical-Optical)

This is most commonly adopted and highly efficient network configuration for the C-RAN Architecture, in this configuration both fronthaul and backhaul is optical fiber of different capacity and configuration. Due to its flexibility and higher channel bandwidth availability this configuration is widely acceptable for the dense traffic urban area where cellular traffic is a growing rapidly. This network is configured to support a large number of RRH unit having many antenna to serve large number of end user who are sharing a common time-frequency resource by taking benefit of mutual co-operation for interference mitigation. To handle this large number of UEs and corresponding antenna the fronthaul and backhaul network used different optical modulation technique with active and passive optical network like Wave length division multiplexing (WDM), CWDM, DWDM ,WDM-PON etc. The optical fronthaul connection is generally based the Common Public Radio Interface (CPRI) protocol that transmit a In phase Quadrature (IQ) data by using a binary modulation technique. Direct modulation technique like IFoF scheme again increase the fidelity of this network configuration.

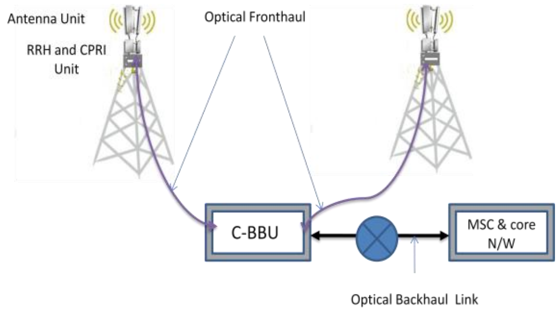

Figure.5. All optical Fronthaul-Backhaul C-RAN Architecture

Since from the design and bandwidth availability point of view, all optical network configurations best suitable for 5th generation cellular network. The next section of this paper discuss in detail about different optical technology for the C-RAN architecture.

III. OPTICAL FRONTHAUL AND BACKHAUL SOLUTION:

As the typical BBU-pool of centralized RAN architecture support 4to50 radio unit simultaneously, I/Q sample required a very high capacity fronthaul as well as backhaul optical backbone with a minimum latency incurred, Radio over Fiber (RoF) is the best option for the deployment of the C-RAN network architecture, optical modulation like Wave length division Multiplexing (WDM),where multiple frequency or wavelength optical signal multiplex and transmit over the same fiber backbone. Based on the optical component characteristic used in the optical network, the whole optical network can be proposed and divided into three broad categories.

- *Passive–WDM Optical Fronthaul and Backhaul Network*
- *Semi passive-WDM Optical Fronthaul and Backhaul Network*
- *Active Optical Fronthaul and Backhaul Network*

A) Passive-WDM Optical Fronthaul and Backhaul Network (P-WDM):

Passive optical network (PON) along with WDM technique, should be a good backbone network for the C-RAN, in term of bandwidth, deployment cost and energy incurred. The P-DWM technology used passive optical component like optical splitter and coupler. A P-WDM network consist of an optical line terminal (OLT) at the BBU pool which provide interface between RRH and BBU unit and also to the core backhaul network, an optical network unit

(ONU) at the remote radio unit (RRH) side, where received radio signal from the antenna unit down converted and interfaced to the optical fiber .The optical splitter, split the incoming optical signal from OLT to the different ONU. The colour RRH-BBU solution is an advance approach where each ONU of a RRH unit of a particular cell used different wavelength of light, and fetch to the corresponding colour BBU- pool OLT [17,19].

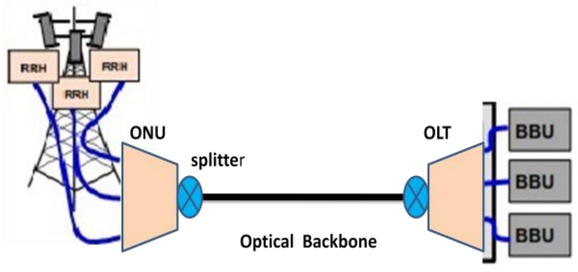

Figure.6.PassiveWDM Optical network for Fronthaul-Backhaul of C-RAN Architecture

The P-WDM network can be range upto 80km without repeater installation, with the used of CWDM this range can be extended upto 120km,the maximum data rate can be achieve with a P-WDM is 40Gbps,with a latency of 5µs.According to the network requirement the P-WDM is of different type like, Broad band passive optical network (BPON),Gigabit enable passive optical network (GPON),and Ethernet capable passive optical network(EPON) and 10 Gigabit enable passive optical network (10GEPON).

B) *Semi passive-WDM Optical Fronthaul and Backhaul Network (SP-WDM):*

The passive optical network can handle 40/80 optical signal simultaneously with a single fiber backbone and achieve very high data rate, but to analyse all the signal simultaneously it required very complex circuit at the OLT and ONU of the optical network, to overcome this limitation an advance Injection locked SFP WDM network (IWDM) is low cost solution is proposed in [18] where an wave length equalization scheme is applied based on a wavelength distinct topology.

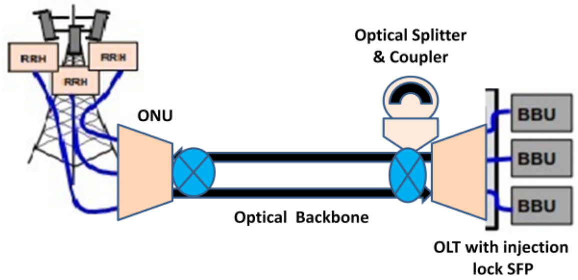

Figure.7. Semi passive WDM Optical network with injection locked SFP for Fronthaul-Backhaul of C-RAN Architecture

The BBU-pool originated some set of optical signal which filtered and routed to the ONU unit of RRH and match with the incoming downlink colour signal and provide a closed path for the incoming signal. This closed architecture simplifies the operation of the optical fronthaul, reduce the cost incurred in the colourless optics and wavelength allocation and increase the CPRI data rate upto2.4Gbps.

C) Active Optical Fronthaul and Backhaul Network (AON):

AON is mostly suitable for the fronthaul connection between RRH and BBU, it used a separate dedicated optical fiber to connect individual RRH unit and each of them are assign with different wavelength. The AON can configured either by Ethernet-optical network, which used Ethernet switch, routers and repeaters along with optical network. The second configuration all optical network ,where the active device like repeaters, connector and switches are of optical type ,which reduce conversion time from electrical to optical (E-O) and vice versa. Due to the limitation electro-optics conversion the data rate is limited to only 1Gbps , where as the implementation of active optical device the data rate can be achieved to 40Gbps.The main disadvantage of AON is required a huge capital cost and having a more complex network structure[21] .

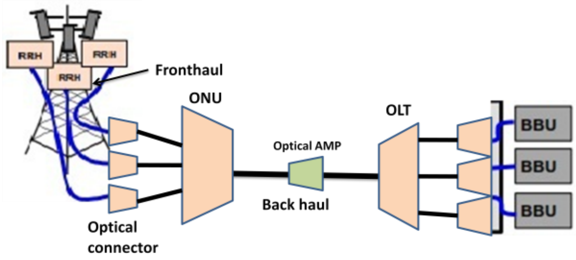

Figure.8. Active Optical network (AON) with injection locked SFP for Fronthaul-Backhaul of C-RAN Architecture

IV. CONCLUSION

The next generation network required a low latency and high data rate for better quality of service (QoS), and this QoS can be achieved by better design and selection of the backbone network. The main objective of this paper is to focus on different challenges and ongoing research work on cellular fronthaul and backhaul network. Depending on the geographical area, bandwidth and data rate requirement the wireless or wire network should be established, microwave link consider being a good alternative for fronthaul network basically for small cell network. Optical network along with the WDM provide a higher channel bandwidth, further the efficiency can be increased by implementation of DWDM, IWDM, hybrid fiber cable and optical active device. In future the implementation of channel assignment, and routing algorithm specially for optical network used at the backhaul network to accommodated increase traffic.

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