The Evolution of Radio Access Network Towards Open-RAN: Challenges And Opportunities

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***Abstract*—The coexistence of massive Internet of Things (IoT) network and modern technologies (e.g., high speed gaming and self driving vehicles) requires a versatile network which can provide support to all such applications. Since the Quality of Service (QoS) requirement of each application is different from one another, the existing Radio Access Network(RAN) is unable to support such diverse applications. Consequently, Open Radio Access Network(O-RAN) is being considered as the most viable solution for next generation RAN. In this paper, we present the evolution of RAN along with the possible architecture and features of the most promising next generation RAN (i.e., O-RAN). This work mainly discusses architectural and functional advancement of the RAN in each generation. In addition, we discuss various challenges associated with O-RAN implementation and possible opportunities created with the advent by O-RAN.**

***Index Terms*—Open-RAN, IoT, Cloud-RAN**

I. Introduction

In the past fifty years wireless communication technology has gone through several transformations [1]- [7]. Specifically, past few decades have witnessed a remarkable growth in wireless communication framework due to the advent of massive IoT and modern real time applications such as high speed video gaming, self driving vehicles, etc [8]- [9]. However, as depicted in Fig. 1, the QoS requirement of each application is different from the other. For instance, connected vehicles demand high speed communication with high degree of reliability [8]. On the other hand, some applications (e.g., IoT) seek low throughput requirement but excellent coverage with low power consumption [9]. In contrast, some applications require low latency and real time data processing. Consequently, the co-existence of such diverse variety of applications require a versatile network which posses all features. Unfortunately, all these targets cannot be achieved by existing/previous RAN which creates the demand of network up-gradation. One way to support such connectivity is to design separate network for different set of applications (shown in Fig. 1). However, it is not a feasible solution from economics and operators respectives. As a result, both the academia and industries are trying to make the mobile network more software driven, virtualized, flexible, intelligent and energy efficient [10]- [11]. Moreover, the network has to be cost efficient and reliable.

Another possible way to fulfil all the given requirements is to split the RAN into various parts based on the functionality. Splitting can make the architecture smarter and versatile. This new architecture is known as Open RAN (O-RAN). Specifically, the advent of O-RAN is a step towards the software oriented infrastructure which enables the network to behave differently according to the QoS requirement of the processed application. From the market view point, O-RAN creates a chance for the small vendors and operators to start their own services and to increase their market revenue [28]- [30]. Though the advent of O-RAN may provide several benefits, there are a number of challenges associated with it. Some of those challenges are as follow:

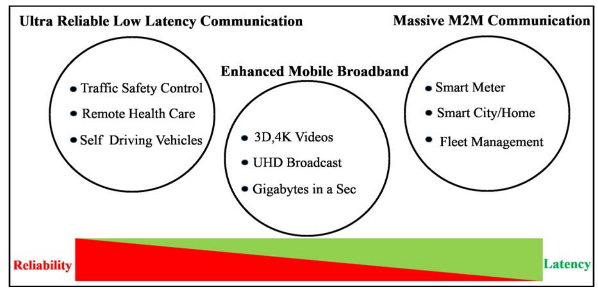

Fig. 1. QoS requirement of various set of applications.

- Due to different QoS requirements, it is difficult to design a stand alone service oriented architecture.
- The network should be flexible to support further upgradations and must be compatible with the existing devices.
- The network should not exert extreme burden on the backhaul and must posses low computational complexity.

In this paper, we present the evolution of RAN along with the possible architecture and features of the most promising next generation RAN (i.e., O-RAN). This work mainly discusses architectural and functional advancement of the RAN in each generation. In addition, we discuss the challenges associated to O-RAN implementation and possible opportunities created with the advent of O-RAN.

II. RAN overview and Evolution

RAN is the major part of the wireless communication system as it connects the user equipment(UE) to the core network by radio connectivity [12]- [13] as shown in Fig. 2 . The basic functionality of RAN is to manage the radio resources [12]- [13]. Thus, typical RAN involves two major unit namely Radio Unit(RU) and Processing Unit(PU) as shown in Fig. 2 .

- Radio Unit: Radio unit contains transceiver antennas and it is responsible for transmission and reception.

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TABLE I
ABBREVIATIONS USED IN THE PAPER.

AI	Artificial Intelligence
BS	Base Station
CoMP	Coordinated Multipoint
CP	Central Processor
CRAN	Cloud Radio Access Network
CU	Control Unit
DU	Distributed Unit
G	Generation
IOT	Internet of Things
IP	Internet Protocol
MAC	Medium Access Control
MEC	Mobile Edge Computing
ML	Machine Learning
MIMO	Multi Input Multi Output
MME	Mobility Management Entity
NVF	Network Function Virtualization
OA	Orchestration and Automation
O-RAN	Open Radio Access Network
PDCP	Packet Data Convergence Protocol
PU	Processing Unit
QoS	Quality of Service
RAN	Radio Access Network
RIC	Radio Intelligent Controller
RLC	Radio Link Control
RRC	Radio Resource Controller
RT	Real Time
RU	Radio Unit
SDAP	Service Data Adaptation Protocol
UE	User Equipment

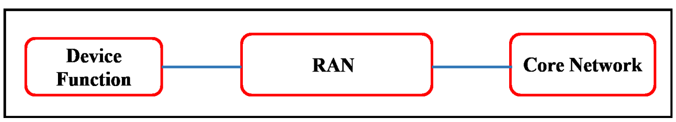

Fig. 2. An illustration of basic RAN

- Processing Unit: Processing unit of RAN is responsible for radio management, resource utilization/sharing and some other operations like (pre-coding, encryption ,etc.).

Fig. 3 shows evolution of RAN over the time. Initially, the number of users as well as data rate requirement was very less. Due to the availability of some data restricted cellular services (e.g., voice call, text messages, etc.), small number of Base Stations(BSs) were sufficient to fulfil this demand. As shown in Fig. 3(a), traditional RANs were equipped with the integrated the RU and PU. Each BS was sufficient to cover the significantly large area. Since the frequency reuse framework was adopted, very less/no computation was required for interference avoidance. Later, RU and Distributed Unit(DU) were separated as shown in Fig. 3(b). The RUs were equipped at the height (usually at the top of tower to support large area) and DUs used to be installed in the room underneath the BS. Fiber optical cable were utilized to connect both the units. Moreover, the introduction of data hungry applications and increase in the number of UEs raised the demand of further densification. However, the densification alone was unable to support such huge data rate demand. Thus, the framework has shifted towards the frequency reuse-1 scenario. Also, the

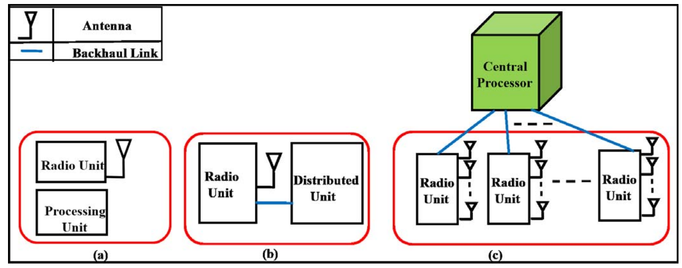

Fig. 3. Different generation of RAN condition

demand of millimeter wave (mm-wave) has been initiated which subsequently raise the demand of connected framework given in Fig. 3(c). The scenario given in Fig. 3(c) is also referred as Cloud Radio Access Network (CRAN) in which PUs of all the BSs are pooled to a standalone CP, formally known as cloud processor [14]- [15].

A. *Key Advancements in RAN*

Some key advancements that have been occurred over the time in the previous/existing RAN are:

1) BS centric to UE centric: Traditional RAN used to associate a BS to a UE on the basis of received signal strength from various BSs (the dominated one selected). This sort of BS selection suffers from the fact that the interfering power received by the cell edge users is usually comparable to the power from serving BS. While, in the UE centric approach, each UE is allowed to choose multiple BSs based on the received signal strength and all these BSs works in a coordinated manner to use/avoid the signal from adjacent BSs. In this way, UE centric approach provides interference free scenario irrespective of user's position [16].

2) mmWave and beamforming: As discussed, BS densification alone could not sufficient to fulfil the ever increasing data rate requirement sufficiently. High data rate also need an extra resources in terms of bandwidth. mmWave spectrum being relatively unoccupied, so it would be a best solution [17]. Though, the incorporation of mmWave has provided several fold increment in the available spectrum, it was challenging to establish a reliable communication over mmWave due to high attenuation and poor diffraction. As a result, multiple antennas can be used at the RUs to form beams in the direction of the intended user [18].

3) Single point to multi point transmission: The traditional networks used BS centric approach to connect each user. Consequently, the edge user suffered from severe inter-cell interference. CRAN has shifted towards UE centric approach which uses several BSs to reduce interference from the other cells [19]. As a result, each UE is served by a cluster of BSs or radio heads which are governed by the CP.

4) Coordinated Transmission: Earlier, several frequency bands used to orthogonalize the adjacent cell users. Due to this, the resource utilization technique was very poor . CRAN utilizes multiple transmitting points to serve each user. This sort of transmission is known as Coordinated Multipoint(CoMP)

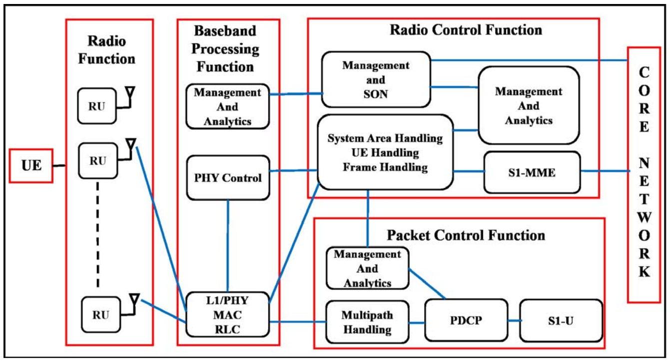

Fig. 4. Expended Version of Future RAN

Transmission. CoMP algorithms are run in the heart of CP which provides coordination among the intra-cluster BSs. Coordinated beamforming, distributed transmission and joint transmission are among some of the popular CoMP techniques [20]- [22].

III. Open RAN: Overview and Infrastructure

According to the latest version of RAN, RAN is basically divided into two units as shown in Fig. 3(c). However,a number of future applications require ultra low latency, more reliable network. Fig.4 shows the internal scenario of RAN, which contain dis-aggregated units like RU, baseband processing function and packet processing function [23]- [26]. This disaggregation enables each unit to perform specific functions and thus, adds flexibility in the network. Basic working of these units can be explained as:

A. Radio Functions at RU

RU contains transceiver antennas along with the special radio hardware which perform physical layer operations (e.g., digital to analog conversion, filtering operation, modulation, etc). In addition, it is also responsible for signal amplification and regeneration [23]- [26].

B. Baseband Processing Function

This unit is responsible for upper layer functions (i.e., radio link control, medium access control) which specifically perform carrier aggregation, soft combining, fast radio scheduling, CoMP operations, etc. Moreover, it is also responsible for selection of MIMO scheme, beam formation and antenna selection [23]- [26].

C. Radio Control Functions

This unit strives to control resource distribution and load sharing among different set of applications and system areas. It is one of the most essential units of RAN and performs virtualization and radio resource management. Basically, it controls the overall performance on RAN based on radio control algorithms [23]- [26].

D. Packet Switching Functions

Like radio control function, this layer plays a key role in virtualization. Specifically, it performs packet processing operations which involve multi-path handling, data scheduling, dual connectivity management and encryption [23]- [26].

Due to dis-aggregation, these all units have a capability to perform a specific task which provides agility to the network. The ultimate goal of RAN is to connect RU (or UE) to the core network. However, traditional network used to treat each application indifferently. In contrast, the connecting path between UE to the core network in O-RAN is decided by the nature of service as depicted in Fig. 4. Some applications/services allow to directly connect to the core network while some are diverted through various stages of radio control function. Moreover, as the depth of transmission increases, the transmission latency also increases which specifically depends on the data carrying capacity of back-haul unit at each intermediate stage. Specifically, management units are responsible to define the intermediate radio connectivity of each service. As a result, the future RAN (i.e O-RAN) becomes highly complex and require ultra large computational capability. However, to overcome such limitations, some modern learning methods and MEC capabilities are being indulged with O-RAN infrastructure. MEC will not only reduce computational complexity at the service plane but also reduce the overall latency [27].

Functions in the traditional RAN architecture that were aggregated into a single node are dis-aggregated in the O-RAN. This distribution increases the reliability by avoiding any single point of failure. Moreover, allowing the separation of control plane and user plane, the control plane function can be implemented on all server platform while specific real time functions can be implemented on the highly specialized hardware. Furthermore, in the O-RAN, the control plane, user plane and transport plane are intended to work independently which increase the scalability and flexibility of the O-RAN. In a nutshell, it can be inferred from the above discussion that O-RAN is the dis-aggregated, virtualized, self driven, application specific and software oriented network which is able to support IoT network as well as modern high speed applications in a stand alone flexible network. The ability to handle multiple radio link protocol interoperability. In the advanced version, some function that are presently handled by radio network layer are planned to move in the IP layer.

The introduction of O-RAN will also have a great influence on market and operators. The deployment of O-RAN could open the doors for public network operators to achieve their core network independent of the existing access network technology [29], which provides the operators the leverage of their core service based network, across variety of technological support. As per economic statistics, the market for RAN based equipment is worth at $30 billion a year and significantly more when smart buildings and vehicular network is included. O-RAN seems to disrupt the network by indulging several innovations and fast creation of flexible inter-operable network. Finally, ORAN design could attract the

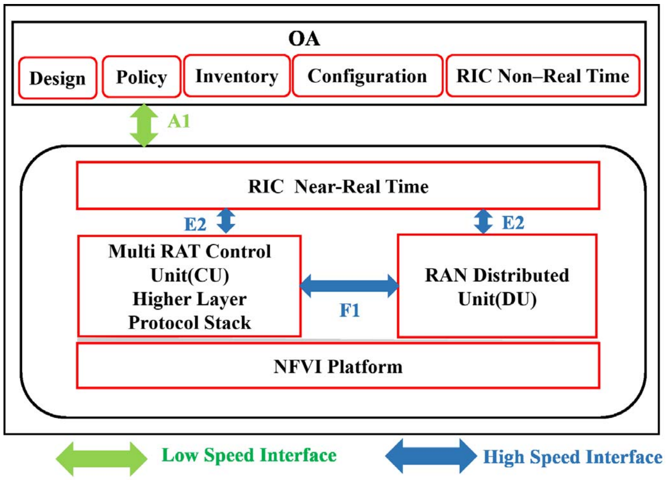

Fig. 5. Reference Architecture of O-RAN

modern business models to incorporate latest wireless services and next generation communication frameworks.

E. Advantages of O-RAN

With the dis-aggregation of hardware and software, O-RAN creates a unified architecture unified architecture through several advancements and brings several benefits (i.e., low latency and network slicing). In addition to facilitating network automation O-RAN provide several benefits given as [31]:

1) Agility: The unification of the software enabled architecture makes the network suitable for existing/past and future generation.

2) Deployment Flexibility: Dis-aggregation and software association makes the network flexible for installation and upgradtion/extension.

3) Real time responsiveness: O-RAN is the software driven service specific network which behaves on the basis of intended service and thus prefers the real time services which require very low latency over the less critical services.

4) Operating Cost Reduction: It is estimated that the plug and play feature of O-RAN and modern learning methods may reduce the maintenance cost upto 80%. Putting the software at the heart of the network, the operators can unify the connectivity gains of all the generations under the same umbrella. Doing this, the operators can save millions of dollars.

F. O-RAN Architecture

Fig. 5 shows a reference O-RAN architecture which is based on the principle of openness [28]- [30]. As discussed in the previous sections that O-RAN is flexible, service oriented and software defined network. Another add on this network is the affiliation of artificial intelligence. Basically the reference architecture of O-RAN includes various sub units. As shown in Fig. 5 , non-real time functionalities are decoupled from the real time function include service and model training for non-real time functionality [28]- [30]. While trained models and real time control functions (produced in real time) are included in the RAN intelligent controller of the near-real time for

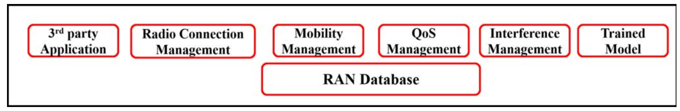

Fig. 6. RIC near-RT

run time execution. RIC near-RT utilizes the database (known as radio network information base) which tracks the state of the underlying network by using E2 and A1. E2 strives to provide a standard interface between RIC near-RT and CU/DU which feeds data that include various RAN measurements for radio resources management. Specifically, the near-RT RIC provides radio management tracked by AI/ML. In addition, this layer is also responsible for operations like handover, QoS management, etc as shown in Fig. 6 . Moreover, the interface AI is responsible for conveying the AI enable policy and ML based training models to the RIC of non-real time. Basically, non-RT control functions strive to support non-real time intelligence radio resource management and providing guidance to support the operations of RIC near-RT functions that are supported by AI interface include [32]:

- Useful data from network to the RIC non-RT to support various requirements such as offline training, online on-line learning AI/ML model, etc.
- Support for RIC near-RT functions such as deploying/ updating ML/AI model into the RIC of near-RT and sometime feedback to ensure that the operators meet the intended objectives.

Fig. 7 shows that dis-aggregated Control Unit stack which is responsible to support various protocols (including 4G, 5G and other protocols). RIC near-RT issues command to implement basic functions (e.g., handovers) virtualization provides the ability to distribute capacity across multiple elements. DU and radio resources unit(RRU) are responsible to support radio functions, radio processing, baseband processing etc [28]- [30].

1) Future Challenges: Some challenges regarding the implementation of model given in Fig. 5 include:

- It is challenging to deploy policies for the RIC near-RT and non-real time control loop meeting the economical and ecological aspects.
- Coordination, updation and training is difficult with the modern learning techniques.(i.e., ML and AI).
- It is challenging to handle data (specifically cross layer data) to support the intended operation while protecting other internal operations.

IV. Technical Advancements and Opportunities

With the acceleration of 5G evolution and O-RAN implementation, several advancements would take place in the modern technologies. Applications associated to IOT devices machine learning, mobile edge computing are expected to reach at the peak in the coming years. Some Key technological advancements and opportunities are discussed below:

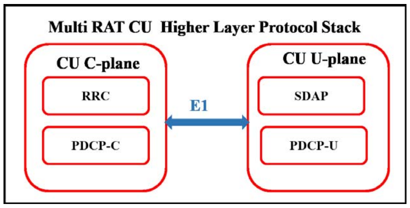

Fig. 7. Control Unit Stack

A. An IoT enabled Network

The launch of O-RAN will remove the restriction in the IoT connectivity. It would provide a flexible architecture, highly suitable for modern IoT connectivity. With this, more things should be connected with various application including health care, retail, security and many more [34].Some new applications may now add on (e.g., digital locks, e-health, etc). Fig. 8 shows some existing and possible applications [35]. Under these applications, IoT devices would be connected over O-RAN framework. Furthermore, disaggregation of RIC non-RT enables to support massive IoT connectivity to the devices which require low throughput but large coverage and low power consumption.

B. Enabling MEC computing

MEC is a form of architecture that enables an edge device to perform computing tasks. Due to rapid increase in the number of connected devices, the next generation RAN should be able to manage the traffic far intelligently. MEC is supposed to a key technique for the same [36] . Currently, most of the applications handle their content storage and online computation on the remote sensors which usually lie far away from the end user. MEC will bring those processes closer to the end user. This shift will help to reduce the congestion on the mobile network and cloud computer. In addition to reducing the congestion, MEC will play a major role in reducing the latency of 5G network [37]. Bringing the data closer to the end unit and streaming it more directly at the end device, extremely low latency can be achieved which enables to support applications that require high speed data and computing.

C. Inclusion of Modern Learning Methods

Machine Learning enables a computer to learn without an explicit program. ML is featured by learning useful information from the input data set, which makes it suitable for the applications in which processing environment is dynamic in nature. Specifically, ML can enhance wireless framework in the following ways:

- ML based resource management, mobility and networking algorithms can significantly adapt the dynamic environment.
- ML is considered as the key to realize the goals of self realizable network.

Fig. 8 shows various ML enabled applications driven by modern learning methods [38]. As per a survey, some machine learning algorithms are already introduced for future wireless

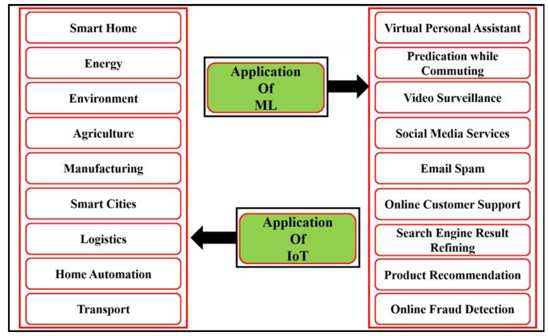

Fig. 8. Applications of ML & IoT

networks, such as Q-learning for resource allocation and interference coordination. In addition, Bayesian learning is used or channel estimation in MIMO network.

V. Conclusion and Future Aspect

The co-existence of variety of applications require flexible, application oriented and adaptive network which are difficult to support on the existing infrastructure. As a result, service providers and mobile operators are moving towards disaggregation of existing RAN. Modern applications require a flexible network which leads to the emergence of building up a standard open interface enabled by AI based network function virtualization. This article explained the evolution of RAN along with background of O-RAN and its reference architecture. The architecture given in this work is a step towards software oriented network. Further we discussed various challenges associated with the O-RAN implementation. Furthermore, opportunities created with the advent of O-RAN have been discussed.

Current version of O-RAN is focused on identifying the radio functions of RAN that can be grouped into functional entities which can be embedded in the distributed system. Specifically, researchers are working on pushing several lower layer functions (i.e., QoS, mobility, management and security) into the upper layer. However, there are some questions and challenges; one issue in O-RAN is to standardize the operation, administration and management because it is difficult to achieve inter-operability without standardization. Although O-RAN seems to provide the required degree of inter-operability, the details are to be work out.

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