Open Radio Access Network challenges for Next Generation Mobile Network

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***Abstract*—Due to the tightly-coupled hardware and software architecture of existing RAN systems and their non-flexibility, disaggregation of software and hardware can bring many unprecedented opportunities regarding enabling the entrance of multiple small-scale infrastructure providers to enter the RAN market, which creates more competitive and innovative RAN ecosystem. Moreover, mobile network operators (MNOs) will also have the advantage of selecting the services according to their network requirements. Open Radio Access Network (O-RAN) builds a multi-vendor RAN ecosystem and utilizes openness and intelligence to address the complexity of network functionalities, increase development agility, and provide more cost-effective platforms due to softwarization and the avoidance of dedicated hardware. However, O-RAN faces many challenges, such as interoperability, convergence, and AI/ML management which still need to be addressed before its wide deployment. This paper surveys the existing issues in the Open RAN ecosystem and explores existing solutions.**

***Index Terms*—Disaggregation, Open RAN, ORAN, Challenges**

I. INTRODUCTION

The significant increase in mobile data consumption has been attributed to the ability of mobile networks to interact with heterogeneous user devices and a wide range of services offered by service providers. To meet the increasing user demands and to provide improved services, next-generation mobile networks are introducing new architectural designs and standards to move toward flexible, agile, and disaggregated system [1]–[3]. Various technologies, such as virtualization and artificial intelligence, are also being introduced in the mobile network that allows network functionalities to be implemented on commercially off-the-shelf hardware and autonomous handling of demanding network activities. This architecture shift enables mobile operators to look for new business models to attract more active users and increase revenue while limiting capital and operational costs.

Such a variety of technologies and services require an open and versatile Radio Access Network (RAN) [4], [5]. However, the existing RAN components are tightly-coupled hardware and software units provided and maintained by a limited number of vendors. As a result, operators face challenges regarding network performance and vendor lock-in. Under such situations, it is challenging to achieve an optimized network that can meet the real-time requirements of network users.

Several solutions have been proposed to address these limitations, but Open RAN has been considered the most feasible solution for next-generation mobile networks [4], [6]. The two main principles of Open RAN are openness and intelligence. The RAN functionalities in Open RAN can be disaggregated into several components and virtualized into commercial off-the-shelf hardware. Open and standardized interfaces allow communication among these disaggregated and heterogeneous units, promoting a multi-vendor ecosystem. These interfaces also allow the integration of data-driven and intelligent closed-loop control for RAN, which can handle complex network-related tasks such as resource management.

The Open RAN Alliance [7], a consortium of industry and academic institutions, is responsible for defining the architecture and specifications for the Open RAN system. Open RAN implements the 3rd Generation Partnership Project (3GPP) functional split [8] to distribute the RAN protocol stack among the Central Unit (CU), Distributed Unit (DU), and Radio Unit (RU).

Related Work and contributions: Prior work has focused on the evolution of RAN [9], [10], in-depth analysis of Open RAN architecture and specifications [4], [10], [11], the capabilities and limitations of Open RAN, highlighting the technologies to address the limitations [1], and implementation of deep learning-based RAN solutions in Open RAN system [5]. To the best of our knowledge, this is the first paper to propose a taxonomy to classify the current Open RAN problems, discuss existing solutions to address these limitations, and then present the findings.

Paper Structure: Section II discusses briefly about Open RAN architecture. Section III presents the challenges in the Open RAN system and its existing solution. Section IV presents the findings of the study highlighting the current position of Open RAN for real-world deployment and concludes the paper.

II. BACKGROUND ON OPEN RAN

Figure 1 represents the general architecture of the Open RAN system. It consists of RAN functions and interfaces specified by the Open RAN Software Community (ORAN-SC) [12]. The architecture contains two groups: the radio group and the management group. The radio group consists of Near-Real Time RIC (Near-RT RIC), Next Generation RAN (NG-RAN) (O-RU, O-DU, O-CU), and ORAN eNodeB (O-eNB) and are

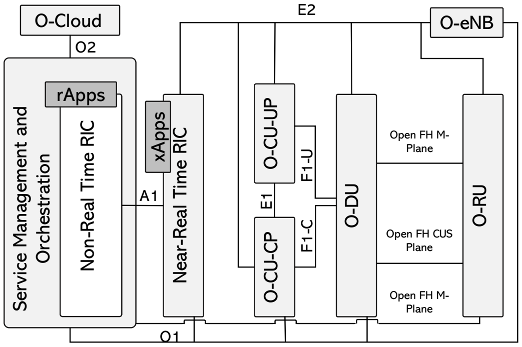

Fig. 1. General architecture of Open RAN system showing key functions and open interfaces defined by Open RAN Alliance.

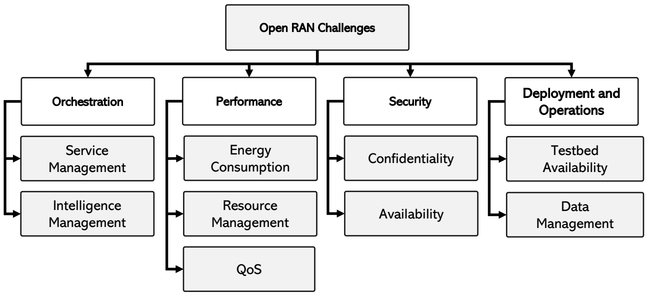

Fig. 2. Taxonomy to categorize current challenges in Open RAN system.

responsible for radio communications. The management group consists of Service Management and Orchestration (SMO) framework and Non-Real Time RIC (Non-RT RIC) and is responsible for system performance and management. Open RAN Cloud (O-Cloud) is a cloud computing platform that hosts the Open RAN functions and software.

III. CHALLENGES IN OPEN RAN AND EXISTING SOLUTIONS

This section categorizes the existing challenges in Open RAN system (Figure 2) into five groups: orchestration, performance, security, development and operations, and standardization.

A. *Orchestration*

The challenges regarding orchestration in Open RAN are categorized into service management and intelligence management.

1) Service Management: Due to the multi-vendor ecosystem, proper deployment and administration of diverse hardware and software are the primary concerns for Open RAN [2], [13]. Although Open RAN Software Community (ORAN-SC) has defined standard interfaces for interoperability between different vendors, there are still concerns regarding operations, administration, and maintenance [14]. Although modularization provides better management of these RAN services [13], selecting the ideal location for the RAN modules remains a significant challenge [3], [15], [16].

To address the issue of RAN functionality placement, the authors in [17] propose a deep learning-based solution to dynamically select an optimal location for network functions to achieve better performance. The authors in [2], [18] propose resource monitoring techniques based on machine learning placed in RICs to determine the ideal location for implementing RAN services. In [15], the authors propose a distributed application called dApps, which can be placed at CU/DU to execute real-time data-driven management and control.

2) Intelligence Management: Intelligence in Open RAN helps address the growing complexity of mobile networks due to an increase in user demand and data usage by embedding intelligence in network and component levels to handle resource management and optimization [6], [19]. However, a challenge for the Open RAN system is orchestrating AI/ML models [2]. There are still concerns about determining the right AI/ML model, choosing an appropriate deployment location and resource requirement, and considering the time scale to make input available [3], [13], [17], [20]. Another major challenge in intelligence management is handling fault prediction (i.e., drifting) of AI/ML results.

The datatype used for AI/ML model and service requirement heavily influence the placement of AI/ML solutions [3], [18]. For achieving low latency and handling user-sensitive data, locating AI/ML services near the edge is the better option, whereas a centralized location could be better for latency-tolerant services [15]. In [2], the authors propose OrchestRAN, an intelligent orchestration framework, to select the optimal location for the RAN function deployment. To address the memory optimization challenges when deploying AI/ML-based network solutions, the authors in [20] propose removing unused program modules and frameworks during the programming phase. The authors in [21] suggest selecting appropriate data for training rather than using all the data for faster convergence of AI/ML model and accurate results. To avoid AI/ML models from giving fault prediction (i.e., drifting), the authors in [22] propose a method for determining whether to retrain a model or switch to a new one. They classified drifting into four types: sudden, gradual, incremental, and reoccurring. A model requires retraining for sudden and gradual drift types, while incremental and reoccurring drift types require selecting a new model.

B. *Performance*

This section discusses the existing challenges of Open RAN regarding performance in three sub-categories: energy consumption, resource management, and quality of service.

1) Energy Consumption: The goal of cellular network design has always been to provide quality network performance while ignoring energy conservation [23]. As a result, the cellular network's RANs consume more than half of its total energy [5]. According to [16], [23], disaggregation of network functionalities of Open RAN into various hardware and the operation of this hardware results in increased energy consumption. Energy efficiency has become a big concern for network providers because the amount of energy utilized is proportionally tied to the operational costs of the network [17], [23], [24].

To address the limitation of energy consumption, the authors in [18] suggest turning off features for small cells during high network load. Another solution presented by the authors is infrastructure sharing which helps to offload additional traffic to less congested cells. The authors in [16] propose a similar idea by introducing an extra DU with a higher processing capacity. According to [25], information sharing among network functions also helps in increasing energy efficiency. The authors deployed sequential multi-agent deep reinforcement learning, concurrent multi-agent deep reinforcement learning, and team multi-agent deep reinforcement learning to evaluate the best solution to achieve optimal network performance regarding power and resource allocation. According to [24], minimizing energy consumption in Open RAN architecture requires the joint selection of optimal DU for network function placement and resource block allocation.

2) Resource Management: The effective allocation and utilization of network resources will be one of the main challenges for the Open RAN system. In the current cellular network, proper management of heterogeneous traffic flow concerning network capacity is still an open issue [26]. Open RAN networks should adapt to the dynamic resource requirement of the network services and users (e.g., network slicing). The growing network traffic also emphasizes the need for an intelligent, automated solution.

RIC applications, particularly xApps, can be used to address the challenges of resource management. The authors in [13] utilize xApps for implementing resource allocation policies. In [18], the authors propose a cell-splitting strategy to reduce traffic congestion in a particular cell. The mobile operators choose network Key Performance Indicators (KPIs) values to determine the cell threshold. In [27], the authors implement a resource allocation xApp for allocating resource blocks for network slices. Since a network slice can contain sub-slices, the intra-slice resource block allocation method helps to distribute resource blocks to each sub-slice. The authors in [26] suggest a dynamic traffic forecasting scheme to forecast future traffic demand in federated O-RAN.

3) Quality of Service: The Quality of Service (QoS) will be a vital element in the Open RAN system, determining the system's performance level regarding user experience. Network operations management, proper hardware-software selection, and continuous monitoring of app-level services are some of the fundamental decisions that contribute to improved QoS [28]. One of the challenges in the Open RAN system is identifying front-haul open interface (connection between O-DU and O-RU) requirements to achieve ultra-low latency [29]. Another challenge is the placement of functionalities in the network ecosystem [2], [15] and scalability [30] to achieve better performance.

The deployment of network functionalities at the edge of the network can help address the traffic congestion at the interfaces [2], [15], [31]. The authors in [3] propose using RIC applications to analyze and optimize key network performance metrics. The authors in [32] utilize power regulation to maximize the overall throughput. The authors in [22] emphasize the significance of continuous monitoring of deployed AI/ML models to achieve good network services to avoid decrease in performance. Roadrunner [33] is an O-RAN-based solution designed to improve cell selection in 5G and beyond networks. In contrast to the legacy cell selection procedure, which prioritizes radio quality and seamless connectivity over high data rates, Roadrunner chooses cells that provide the best performance rather than just the best radio connectivity, even if a candidate cell with better radio connectivity is available.

C. Security

The existing challenges of Open RAN regarding security are discussed in two sub-categories: confidentiality and availability.

1) Confidentiality: The introduction of RICs enables intelligent solutions in the form of xApps and rApps to handle complex network activities. These solutions require substantial information from the lower network level, such as DUs, for training and accurate prediction. The information generated at DU contains user-sensitive information which could get exposed when shared with RICs [15]. Moreover, the multi-vendor ecosystem of Open RAN might also create confidentiality challenges when handling such user-sensitive data [34], [35].

Decentralized applications (dApps) [15] can be deployed in DU to handle real-time control loops to address the limitation of user-sensitive data sharing. The authors in [35] propose an intelligent zero trust architecture (i-ZTA) that utilizes AI/ML for information security in an untrusted network. The fundamental elements of i-ZTA are the policy enforcement point (PEP) and policy decision point (PDP) that utilize intelligence to make access decisions.

2) Availability: Although RAN functionality disaggregation could provide numerous technological and performance benefits, system availability remains a critical challenge that must be addressed [36]. The introduction of open markets and interfaces, as well as the virtualization of RAN functions, raises security concerns about the hardware and software [37]. The location of RAN functionalities has a significant impact on availability in an Open RAN system. The RIC applications may also affect availability. Because xApps and rApps handle critical control loops, these applications must be resistant to outages [38].

To address the limitation related to location, the authors in [36] propose a Binary Integer Programming (BIP) optimization model to select deployment location for software Open RAN functions in O-Cloud. In [37], the authors propose creating backup servers for each virtual RAN function which could take over responsibility for the failed server. The authors in [38] provide the RIC Fault Tolerant (RFT) framework for making the applications fault-tolerant during programming.

D. Deployment and Operations

The existing challenges of Open RAN regarding deployment and operations are discussed in two sub-categories: testbed availability and data management.

1) Testbed Availability: There is a lack of an end-to-end testbed for the Open RAN system to implement and test various use cases [3], [39]. The ORAN Software Community provides individual code bases for Open RAN functionalities and interfaces (RICs and SMOs). However, there is no clear guidelines for integrating these functionalities with existing implementations from other open-source communities such as OpenAirInterface, and Magma core.

The authors in [40] propose Open RAN Gym, a testbed with end-to-end design for testing intelligent solutions for next-generation Open RAN systems. Open RAN Gym utilizes srsRAN for software RAN functionality. The srsRAN protocol stack is extended with the SCOPE framework [41] to add more networking functionalities. It utilizes Colosseum [42] as the data factory and ColO-RAN [43] to implement Open RAN control architecture. The same authors propose a similar approach in [3], but CellOS [44] is utilized for extending srsRAN implementation, and Open RAN Software Community provides RIC functionalities.

2) Data Management: Data management will be essential for all AI/ML activities in Open RAN system. A key challenge lies in storing, categorizing, and selecting the data related to RAN according to the use-case requirement. Another challenge lies in access to proprietary data owned by the base station owners, which is difficult to share due to privacy and competition concerns [3], [45]. Furthermore, there is also a lack of open-source data for research purposes.

Colosseum [42] and Arena [46] could be used to extract data sets based on real-world network scenarios in order to address data availability issues. The works of [2], [3], [40] utilize Colosseum to collect data sets for research purposes over various timeframes. In [45], [47], the authors propose relying on diverse data sources such as access points, cameras, and Wi-Fi access points to extract contextual information from a specific location. Another option is to work with mobile operators to obtain data sets [18].

IV. Lessons Learned and Future Direction

In this section, we summarize lessons learned and future directions for adopting Open RAN services for next-generation networks (NGNs).

A. Lessons Learned

One major challenge in adoption is finding a **balance between system performance and complexity** because a high-performance requirement may result in a complicated system architecture. On the other hand, a less complex design may result in a system with lower performance [9]. Another challenge during Open RAN adoption is the **convergence** between third-party services. These services must also be highly standard-compliant, interoperable, stable, and secure. These functionalities, once deployed, should be resistant to vulnerabilities such as system failure, security breaches, and policy violations. Another challenge for Open RAN systems during adoption is to become more, if not equally, **energy-efficient** as traditional RAN architecture. MNOs and smaller service providers should focus on energy efficient technology and regularly monitor the hardware and software performance indicators for energy optimization.

In contrast with conventional RAN systems, Open RAN systems will have more **security challenges** in architecture and supply chain because of disaggregation, open interfaces, and third-party application services. The multi-vendor ecosystem could create more security overhead or risks, so it will be essential to understand the risks and find the techniques to solve them. The Open RAN alliance has a dedicated work group to identify the threats and define policies to address them. Another challenge in adopting Open RAN in NGNs is increasing **operational costs** due to multi-vendor management and maintenance. Although the Open RAN system aims to reduce overall RAN costs, operational costs may rise due to multi-vendor management and the need for continuous setup and main- tenance processes even after deployment. As a result, it is critical to continuously monitor the system and look for ways to cut costs. **Adapting to the changing ecosystem of cellular networks** can be another challenge to Open RAN systems as third-party services need to continuously update their services according to network changes.

B. Future Directions

Addressing the above mentioned challenges could be a step forward in adopting Open RAN in NGNs. For instance, Open RAN systems could benefit from continuous integration and monitoring culture and test-driven development approach. Rural areas can be suitable testing locations because they face less risk affecting network performance and user experience during testing. Other locations could be indoor deployments such as testbeds and Digital Twin [48], which could simulate the current network scenario to identify and resolve issues before they occur.

New businesses can enter the cellular market by targeting existing and stable cellular networks to deliver solutions and later adapt to future network generation requirements. Currently established vendors could provide their expertise to new and small scale providers to help expand their services in the marketplace.

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