UDC: 621.39
DOI: http://dx.doi.org/10.7708/ijtte2023.13(1).06

THE FUTURE OF OPEN RAN

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Received 20 January 2023; accepted 27 February 2023

Abstract: The entire telecom industry is going through a change that can be only compared to the change that data centers went through in the 2000s, both driven by Moore's Law. Open RAN is a crucial enabler of this transformation, allowing building networks to use a fully programmable software-defined RAN solution based on open interfaces that run on commercial, off-the-shelf hardware. This paper aims to present the O-RAN from a theoretical perspective, the pros, and cons of the O-RAN for mobile network operators and try to answer if the future of the RAN is going to be open.

Keywords: Open RAN, 5G, virtualization, functional split, energy efficiency.

1. Introduction

RAN (Radio Access Networks) components should be open as they are based on 3rd Generation Partnership Project (3GPP) standards, but they have consistently been closed, in that a Mobile Network Operator (MNO) had to buy every part of their RAN from the same vendor for it to function. Parallel Wireless (2020) noted that MNO cannot install vendor B's software on a Baseband Processing Unit (BBU) from vendor A or connect a remote radio unit (RRU) from vendor A to a virtualized BBU hardware and software from vendor B due to lack of interoperability. There have been several attempts to change this so-called vendor "lock-in", but they all failed since it wasn't in the vendor's interests to support them.

From 3GPP TS 38.300 (2022) it's clear that the complexity of cellular networks is constantly growing. New developments include massive Multiple Input, Multiple Output (mMIMO), Active Antenna Unit (AAU), millimeter wave and sub-terahertz communications, private networks, Machine Learning (ML) and Artificial Intelligence (AI) applied in digital signal processing. According to Polese *et al.* (2020) this will impose increasing capital and operational costs (CapEx and OpEx) for the network operators, which will have to continuously upgrade and maintain their infrastructure to keep up with the new market trends and customer requirements.

Recently, researchers have shown that RAN participates with almost 60% in CapEx and OpEx. Polese *et al.* (2023) noted that Open RAN (O-RAN) as a new paradigm for the RAN of the future may be viewed as a potential solution for increasing RAN costs. The term "Open RAN" is used to refer

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to the overall movement of opening RAN by disaggregating hardware and software and creating open interfaces between them. In turn, "OpenRAN" is used by Telecom Infra Project, while O-RAN with a "dash" or hyphen is used by the O-RAN Alliance. According to iGR (2021), the primary benefits promised by O-RAN are:

- Lower CapEx/OpEx costs compared to legacy RAN;
- Enabling new services. O-RAN should accelerate operators' ability to emulate cloud companies devising and delivering new services very quickly and responsively, and by harnessing a service platform that is flexible, but also automated and simple to operate;
- Use best-of-breed components and software architecting to build the infrastructure for the network;
- Lower deployment times. Using virtualized RAN, benefits like automation can reduce the average time for deploying a site. And a virtualized RAN combined with centralization can be deployed faster than a traditional architecture since the only site installation required is for the radio and power;
- Minimizes vendor lock-in danger. The incoming O-RAN vendor's equipment is expected to work with the incumbent and future vendors' solutions;
- Ability to add massive scale if needed using a web-scale approach.

To help the reader to better understand why O-RAN is being considered as future of the RAN, we will start by explaining the difference between the virtualized RAN (vRAN) and O-RAN concepts, since they are often used in conjunction with each other, and sometimes confusingly.

2. vRAN vs O-RAN

Checko *et al.* (2015) consider that virtualization of the RAN functions has begun in 2011 with the Cloud/Centralized RAN (C-RAN) initiative from IBM, Intel, and China Mobile. Gavrilovska *et al.* (2020) stated that both centralized and cloud RAN have the goal to move BBU to a centralized location to save rental costs and reduce power consumption. Peng *et al.* (2015) shown that C-RAN requires a new high-bandwidth, high-reliability, and low-latency interface between RRU and BBU. Common public radio interface (CPRI) and the Next Generation Fronthaul Interface (NGFI) evolved to enable this. C-RAN offered an option to further split BBUs into Distribution Unit (DU) and Central Unit (CU). As shown in Figure 1, CU is further toward the core network resulting in a new interface called midhaul (MH). C-RAN wasn't necessarily open, but it did begin the movement toward disaggregating the RAN. According to Azariah *et al.* (2022) C-RAN issues such as huge FH overhead, fiber access requirements and security problems forced the industry to shift focus on vRAN.

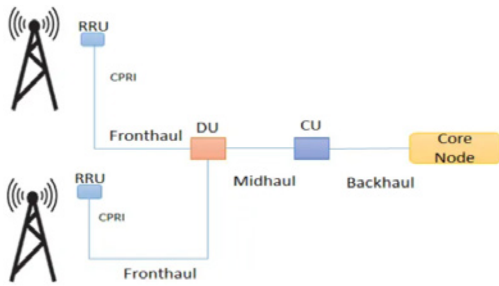

Fig. 1.
C- RAN with BBU Split
Source: (TelcoCloudBridge, 2023).

Ying (2018) defines vRAN as the decoupling of software and hardware through virtualization technologies such as network function virtualization (NFV) or containers for deploying CU and DU on x86 server. Wypiór *et al.* (2022) pointed out that even if RAN functions are virtualized on a COTS server, the interface between the BBU and RRU is not necessarily an open interface, so vRAN can still create vendor lock-in.

Table 1
Types of Virtualized RAN Platforms

Name	Characteristics	Vendors
"Truly" O-RAN	• open interfaces, • cloud-native, • disaggregated, • multi-vendor, • virtualized.	1. Altiostar, 2. Mavenir 3. Parallel Wireless, 4. JMA Wireless
Pre-integrated O-RAN	• open interfaces, • cloud-native, • not disaggregated, • single or multi-vendor, • virtualized.	1. Rakuten Symphony
(Partly) appliance-based O-RAN	• open interfaces, • not or only partly cloud-native, • not disaggregated, • single or multi-vendor, • not or only partly virtualized.	1. Fujitsu 2. NEC 3. Nokia
vRAN	• open or proprietary interfaces, • cloud-native, • not disaggregated, • single or dual-vendor, • virtualized.	1. Samsung 2. Ericsson 3. Nokia
C-RAN	• open or proprietary interfaces • not disaggregated, • single-vendor, • VM-based or part VM/part appliance.	1. Nokia 2. Ericsson 3. Huawei

The key with O-RAN is that the interface between the BBU and RRU is an open interface, so, any vendor's software can work on any open RRU. Parallel Wireless (2020) stated that MNO can virtualize and disaggregate its RAN, but unless the interfaces between components are open, the RAN cannot be considered as truly open. Nevertheless, some of the open RAN implementations are designed as a pre-integrated solution, with only one or two vendors participating. Additionally, few of the incumbent RRU and BBU vendors offer partly appliance-based O-RAN solutions. In practice, the boundaries between C-RAN, vRAN and O-RAN are overlapping and sometimes disputed. Types and characteristics of virtualized RAN platforms supported by different vendors are presented in table 1.

3. O-RAN Main Drivers

Two leading organizations are driving O-RAN development today: O-RAN Alliance and Telecom Infra Group (TIP). TIP's OpenRAN project mission is to accelerate innovation and commercialization in RAN domain with multi-vendor interoperable products and solutions that are easy to integrate with the MNO network and are verified for different deployment scenarios. TIP's OpenRAN program supports the development of disaggregate and interoperable 2G/3G/4G/5G RAN solutions based on service provider requirements. TIP collaborate with other industry organizations, including Open Networking Foundation (ONF), Groupe Speciale Mobile Association (GSMA), and ORAN Alliance. An essential step in developing the O-RAN ecosystem was an alliance agreement between the TIP and ORAN Alliance, which allows the two groups to share information, reference specifications and conduct joint testing and integration efforts.

The O-RAN alliance is the other main driver of the O- RAN concept, focused on efforts to specify the overall architecture, management and orchestration interfaces, Radio Intelligent Controller (RIC), use cases, etc. The O-RAN Alliance was founded in 2018 by AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO and Orange. While The O-RAN Alliance develops, drives, and enforces standards to ensure that equipment from multiple vendors inter-operates with each other, TIP is more deployment and execution focused. TIP encourage Plugfests and live deployments in the field, and it's been responsible for the productization of use cases, facilitates trials, field testing and deployment.

According to Rimedo Labs (2021), besides O-RAN Alliance and TIP, important O-RAN contributors are Open Networking Foundation (ONF) with its software-defined RAN (SD-RAN) and O-RAN Software Community (OSC) created by O-RAN Alliance and Linux Foundation. SD-RAN is developing a near-real-time RIC and a set of exemplar xAPPs controlling the RAN, while OSC aims at creating an open-source software reference design for the whole O-RAN.

4. O-RAN Architecture and Functional Splits

In the traditional 4G architecture, the split point between the DU and RRU was such that up to 600Mbit/s of fronthaul interface was required per 10MHz of a radio channel. Per 3GPP 38.300 (2022) in 5G the radio bandwidth will increase to 100MHz and above. Caroline *et al.* (2021) predicted that the introduction of a large number of antenna elements for mMIMO antennas will lead to untenable fronthaul bandwidth requirements of 100Gbit/s–1Tbit/s. To support this, 3GPP has introduced an enhanced-CPRI (eCPRI) interface with an increased number of functional splits in order to reduce the overall fronthaul bandwidth. According to Checko *et al.* (2018), functional splits refer to the points along the protocol stack where CU and DU signal processing can be separated from the RU. As shown in Figure 3, 3GPP specifies eight functional splits for the eCPRI, where parts of the DU's functional electronics can be placed together with the RU. Within the eight main functional split options, option 7 further divides into sub-options 7-1, 7-2 and 7-3.

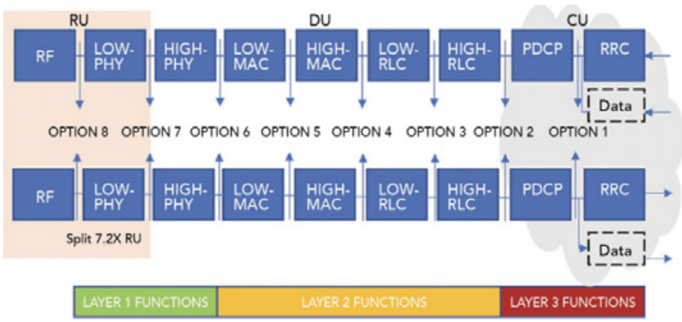

Fig. 3.
3GPP Functional Split Options for the 5G
Source: (3GPP, 2022).

To support increasing FH bandwidth O-RAN fronthaul specifications include a new provision for functional splitting called Split Option 7-2x. An overview of Split Option 7-2x is shown in Figure 4. Umesh *et al.* (2020) showed which Layer 1 functions traditionally located in the BBU are placed in radio equipment using Lower Layer Split (LLS). LLS also prescribe detailed signal formats and equipment operation required for multi-vendor RAN hasn't been prescribed eCPRI specifications and Management Plane (M-Plane).

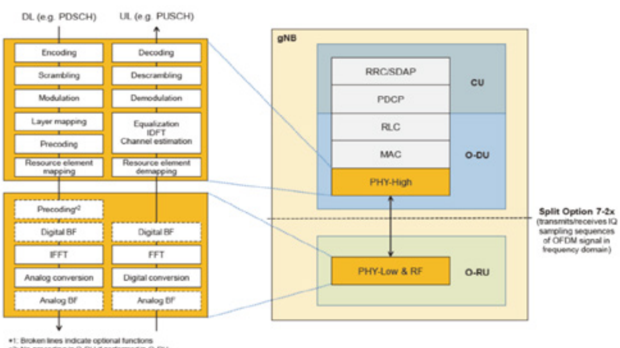

Fig. 4.
Split Option 7-2x adopted in O-RAN
Source: (Umesh et al., 2020).

O-RAN WG1 (2021) put great effort to design flexible O-RAN architecture, consisting of different nodes and interfaces along with various options for implementation. The main building blocks in O-RAN architecture are presented in Table 2. Separate vendors can provide them; thus, they can create an ecosystem of players developing only CUs, DUs, or only xAPPs or RICs.

Table 2

O-RAN Architecture Building Blocks

Name	Short Description
O-Cloud	Cloud Computing platform comprising physical infrastructure nodes to host O-RAN functions, like near RT-RIC, O-DU, etc.; supporting software components (e.g., operating systems, virtual machine monitoring, container runtime), management, and orchestration functions.
O-RU (O-RAN Remote Unit)	A logical node hosting a low-PHY layer functions
O-DU (O-RAN Distributed Unit)	A logical node hosting RLC (Radio Link Control) /MAC (Medium Access Control) and high-PHY layer functions.
O-CU-CP (O-RAN Central Unit-Control Plane)	A logical node hosting RRC (Radio Resource Control) and CP (Control Plane) part of PDCP (Packet Data Convergence Protocol).
O-CU-UP (O-RAN Central Unit-User Plane)	A logical node hosting SDAP (Service Data Adaption Protocol) and UP (User Plane) part of PDCP.
near-RT RIC (near Real-Time RAN Intelligent Controller or nRT RIC)	A logical node, enabling near-RT control and optimization of RAN elements and resources via fine-grained data collection and actions over E2. Near-RT RIC may include AI/ML workflow.
non-RT RIC (non-Real-Time RAN Intelligent Controller or NRT RIC)	A logical node, enabling non-RT control and optimization of RAN elements and resources, capturing AI/ML workflow, and policy-based guidance of application features in NRT RIC.
xAPP	An application designed to run on near-RT, likely to consist of one or more microservices, that identifies data to consume and provide. xApp is independent of nRT RIC and may be provided by a third party.
SMO (Service and Management Orchestration)	System supporting orchestration of O-RAN components that includes NRT RIC.

Source: (O-RAN Working Group 1, 2021).

5. O-RAN Security and Energy Efficiency

While Open RAN architecturally disaggregates the RAN, it also increases the potential security attack surface. Mimran (2022) recognized five risk areas which are the most relevant to the O-RAN: cellular infrastructure, architectural openness, cloud and virtualization, machine learning and 5G architecture. Liyanage *et al.* (2023) stated that O-RAN as a multi-vendor approach will bring a new set of potential risks and threats to the MNOs. From an architectural point of view, LLS will introduce a potential new attack surface in the RAN which needs to be properly addressed. Fujitsu (2022) believes that security risks can be only mitigated with a combination of people, processes, and technology.

In the past 3 years, O-RAN Alliance puts a great effort to help MNOs evaluate security in the O-RAN by developing detailed specifications for security requirements, protocols, and threats, as well as testing and integration procedures. Some of the most important threats defined by WG11 (2022) are listed in table 3. Security Task Group (STG) from O-RAN Alliance recommended to use of industry security best practices such as TLS and SSH to protect O1 and Open Fronthaul M-plane interfaces. Rakuten Symphony (2022) stated that MNOs should leverage the knowledge and experience of cloud operators who are already been faced with similar security challenges. In the long term, the openness of O-RAN should be considered as an advantage from the security point of view, since it has been proven that open systems can be more vulnerable initially, but they become securely as a proprietary system at a later stage.

Table 3
Threats against O-RAN

Category	Type of Threats
Threats against O-RAN system	1. Common among O-RAN components 2. Against the fronthaul interface and M-S-C-U planes 3. Against O-RU 4. Against Near-RT RIC 5. Against Non-RT RIC 6. Against xApps 7. Against rApps 8. Against Physical Network Function (PNF) 9. Against SMO 10. Against A1 or R1 interface
Threats against O-CLOUD	1. Generic threats 2. Threats concerning VMs/Containers 3. Threats concerning VM/Container images 4. Threats concerning the virtualization layer 5. Threats concerning O-Cloud interfaces 6. Threats concerning hardware resources 7. Threats concerning O-Cloud management
Other	1. Threats to open-source code 2. Physical threats 3. Threats against 5G networks 4. Threats against ML system 5. Protocol stack threats

6. O-RAN Energy Efficiency

In addition to security, energy efficiency (EE) is becoming a key requirement for today's mobile networks. EE is defined as a ratio between the average user throughput and average power consumption and can be understood as an end-to-end requirement which involves all domains of Open RAN. Some of the prerequisites for energy-efficient O-RAN networks are power-efficient hardware, well-defined EE Key Performance Indicators (KPIs), and ML/AI utilization to optimize and automate energy efficiency.

According to Deutsche Telekom (2021), EE should not degrade the quality of service or have an impact on the main O-RAN concepts such as cloudification and disaggregation. Hoffmann *et al.* (2021) proposed several approaches to improve EE in mobile networks, ranging from the whole base station going to sleep mode up to the resource element or pilot signal level. Rimedo Labs (2023) considered cell on/off switching implementation in the form of rApps. The same authors offered the RF channel switching concept as a part of a slow control loop in the non-RT RIC. Imoize *et al.* (2022) has shown that fractional power control and ML-based power allocation schemes can decrease power consumption.

With 70 to 85% of the energy consumption in a mobile network coming from the RAN, the overall objective for Open RAN networks is to gradually become more energy efficient than traditional RAN. A lot of companies are already working on this challenge, resulting in O-RAN energy efficiency and savings use case creation. However, true RAN sustainability will require continued strategic collaboration from both vendors and operators.

7. The Current State of O-RAN Deployment

The O-RAN concept and movement are not new, MNOs and hardware/software vendors have been developing solutions, conducting trials, and deploying networks for the last few years. iGR (2021) identified 23 publicly announced MNOs worldwide using equipment from multiple vendors, including Altiostar, Mavenir and Parallel Wireless. The motivation for many large operators to start with O-RAN trials was to try to resolve integration and operational challenges as well as to explore different use cases and the role of O-RAN as a "disruptive" technology alongside the existing network.

O-RAN Alliance (2021) introduced the initial set of use cases and cloud-native deployment support options. Today, there are many potential use cases for O-RAN, which the trials, pilots and limited rollouts have been addressing: greenfield or brownfield macro networks, private networks, underserved regions in developing markets, urban coverage densification in developed markets, rural broadband, indoor coverage, and many other. In recent research Brown (2021) showed that for public macro networks, MNOs will prioritize O-RAN deployment with 25%, 34% and 41% for urban, suburban, and rural cell site types respectively. Emmelmann *et al.* (2022) believes that even though an O-RAN concept was invented by global MNO, nowadays it's highly applicable for campus networks.

However, even for the most viable open RAN use cases, vRAN offers an attractive option with proven benefits like cost efficiencies, flexibility, scalability, automation, and a technology platform for innovative, cloud-based services. Because of this, a more obvious case for O-RAN in developed markets is in greenfield networks. Here, we have seen significant deployments like Rakuten Mobile in Japan and Dish in the USA with 1&1 Drillish in Germany to follow (launch expected in summer 2023). Rakuten Symphony has proven that O-RAN and fully virtualized cloud native networks are possible in high-density coverage areas. Tecknexus (2022) announced that Rakuten Mobile has completed 97% population coverage in Japan using 275,000+ live cells from 9 different radio vendors, managed only by 250 engineers, and with 40% and 30% independently verified cost savings on OpEx and CapEx respectively.

8. Conclusion

O-RAN is not a completely new technology, but rather a collective term for current technologies such as virtualization, open interfaces and flexible system administration using ML and AI (Artificial Intelligence). The legacy RAN vendors have provided proprietary solutions and continue to promote and deliver closed systems in their best interests. Ecosystem challenges, cumbersome and costly RAN swap, deployment cost and flexibility, and lack of innovation are some of the main challenges that drive MNO to consider O-RAN as a new approach to design and build their RANs. Still, there are some challenges associated with an O-RAN concept: MNO can't use the "one neck to choke" approach anymore; O-RAN standards are not currently widely adopted; and O-RAN vendors are few 3GPP releases behind the legacy vendor regarding network performances and supported features. For most potential use cases of the O-RAN, there are vRAN or C-RAN alternatives ready to go without the integration and operational problems associated with the O-RAN.

Hardware and software vendors, system integrators, ORAN Alliance, TIP, and other organizations are putting great effort into overcoming these challenges. The emergence of disaggregated vRAN technology is driving interest in Open RAN, but both are in the early stage in terms of commercial deployments. As of now, Rakuten in Japan and Dish Networks in the USA are the only two large-scale O-RAN deployments, and O-RAN success depends heavily on the success or failure of these two networks.

The future of O-RAN should be more transparent in upcoming years. The expectation is that Open RAN macro networks will be adopted only slowly until the end of 2023 as operators wait for the platforms to mature. Prospective O-RAN business case can be multi-G consolidation and 4G rollout for remote and under-served regions in developing markets, but this is not so relevant for most developed markets. In the future, based on the business case, we can expect MNO's first choice to be vRAN or O-RAN, with O-RAN gradually gaining market share. However, until then, some O-RAN challenges still need to be overcome.

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