Evolving Open RAN Interoperability: A Large-Scale Definition

Aziz Kord, Vu Le, Jason B. Coder
Communications Technology Laboratory
National Institute of Standards and Technology
325 Broadway, Boulder, CO 80305 USA

Abstract—**Open RAN technology has tremendous potential to spur innovation, increase competition and flexibility, and reduce the cost of cellular systems. Today, the interoperability of the Open RAN ecosystem is one of the most significant challenges facing this technology. It is potentially keeping it from being accepted by cellular providers and businesses. This paper intends to *redefine* Open RAN interoperability scientifically and comprehensively. The foundations of this new definition are laid out here. This new definition of interoperability aims to help consolidate the numerous definitions that exist today and lay the groundwork for new measurement methods that can be used to quantify the interoperability of hardware and software. We leverage pieces of definitions from existing Open RAN sources and then expand the definition to promote large-scale testing. The current definition of interoperability using Plugfest may be a first step, but it is not enough to widely accept Open RAN devices in the cellular community. The definition presented here will reduce the misunderstanding among Open RAN commercial entities, standards bodies, and researchers and provide a foundation for new measurement methods.**

I. Introduction

Open Radio Access Network (Open RAN) is a new network architecture in the cellular network that enables multi-vendor deployment of radio access network (RAN) components, allowing operators to mix and match products from different manufacturers. The Open RAN concept has multiple goals: reduce the cost of deploying mobile networks, improve the flexibility of the network, promote innovation, and leverage new artificial intelligence (AI) and machine learning methods within the RAN. Mobile network operators (MNOs) and other customers of the cellular systems see the opportunity to use the Open RAN technology to increase their network's flexibility with new features and optimization [1]. At the same time, there are additional possibilities for innovation in the cellular industry. An example would be the innovation zones designated by the United States Federal Communication Commission [2].

Although the multi-vendor ecosystem is one of Open RAN's advantages, it is also one of its disadvantages. Multi-vendor architecture creates interoperability, complexity, and management challenges compared to legacy RAN architectures provided by a single vendor offering a unified support structure. In contrast, Open RAN integrates components from multiple vendors, leading to a more heterogeneous network environment.

The success of this fledgling architecture is heavily predicated on the ability of network components to be interoperable [3].

This increased complexity can pose system interoperability, deployment, troubleshooting, and ongoing maintenance challenges. MNOs may need to invest more resources in managing and coordinating diverse components, potentially resulting in higher operational costs. The need for interoperability testing and resolving compatibility issues between different vendors' equipment can also introduce delays in deployment and upgrades to the Open RAN system [4] [5].

To ensure interoperability in Open RAN networks, industry organizations like the O-RAN Alliance, 3rd Generation Partnership Project (3GPP), Open Network Foundation (ONF), and Telecom Infra Project (TIP) have defined open interfaces and common standards with the goal of enabling different vendors' equipment to work together while also ensuring performance. These interfaces and protocols enable operators to deploy Open RAN networks using equipment from multiple vendors [6]. While the established definitions of interoperability facilitate conceptual discussions and the development of new components, additional work is necessary to add rigor, which can then lead to new means of scientifically quantifying interoperability.

This paper discusses the definitions of interoperability from different organizations and their advantages and disadvantages. We then introduce a new definition of Open RAN interoperability based on key performance metrics and examine the level of interoperability between different components and systems within an Open RAN network by varying parameters within the system to measure Open RAN interoperability scientifically. This new definition lays the foundation for defining interoperability in a way that promotes large-scale, independent testing of hardware and software.

II. Open RAN System

The Open RAN network is a new telecommunication architecture aiming to decouple the RAN's hardware and software components. This enables each component to be supplied by a different vendor.

In Open RAN, the base station is essentially a disaggregated legacy RAN base station combined with RAN network slicing similar to the 5G core (5GC) for customizing the base station function. This difference is illustrated in Fig. 1.
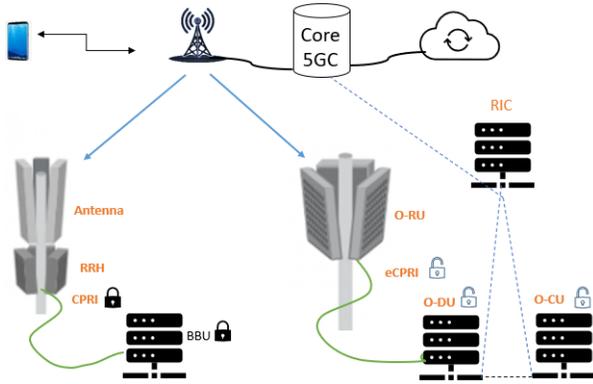
Fig. 1: A comparison between legacy and Open RAN topologies.

The new Open RAN base station design is disaggregated into three parts: central unit (CU/O-CU), distributed unit (DU/O-DU), radio unit (RU/O-RU), and a new node added called a RAN intelligent controller (RIC). The RIC's function is to enhance the allocation of RF resources in real and non-real-time using AI. These four parts are shown in Fig. 1. The legacy base station protocol layers are divided among the DU, CU, and RU: The CU is responsible for non-real-time layer 2 (L2) functions. The DU is responsible for the real-time physical layer (L1). The RU is responsible for transmitting and receiving data and generating the RF signal. Finally, RIC is responsible for reconfiguring the system dynamically to optimize performance [7].

Exactly how interoperability is defined between the components of the Open-RAN system will be discussed in detail in the remainder of this paper.

III. OPEN RAN INTEROPERABILITY

To promote the large-scale development of Open-RAN, a scientifically rigorous definition of interoperability that enables vendors to test their own products is needed. Currently, there are multiple definitions. No single definition satisfies the need for a commercial Open RAN deployment. In addition, the Open RAN stakeholders may have different perspectives on what Open RAN interoperability means and how it should be achieved based on their involvement and view in the Open RAN technology.

Several organizations have defined interoperability based on their role and view in the Open RAN community. The O-RAN Alliance refers to Open RAN interoperability as the ability of different RAN elements from other vendors to work together seamlessly and standardized [8]. The functional aspect of Open RAN is an important aspect of interoperability but does not fully guarantee the operation of equipment in the field.

The Telecommunications Industry Association (TIA) defines Open RAN interoperability as the ability to adapt to global policies. This definition is a high level and may be an excellent first step. Still, it needs additional tests to verify all system components work together in all conditions and meet the performances acceptable by MNOs [9].

The European Telecommunications Standards Institute (ETSI) defines Open RAN interoperability as the ability of RAN components from different vendors to communicate and operate together, conforming to specified interfaces and meeting performance requirements [10]. Conforming to the standard is the first aspect of interoperability. At a deeper level, interoperability expands beyond basic compliance testing.

The Small Cell Forum defines Open RAN interoperability as the ability of RAN components from different vendors to operate together seamlessly and without service interruption [11]. This definition isn't clear on what service interruption is or how it can be quantified.

The definition of interoperability differs in TIP than in other organizations because TIP is responsible for defining and designing interoperability test cases for validating and "badging" the open RAN software and hardware manufacturers. Badges are given to entire end-to-end systems or groups of devices that show interoperability with each other, not to the other vendors [12]. This solution provides some confidence for NMOs, but given the number of different combinations of vendors and components, it isn't practical to test and badge every one of them. This effectively limits NMOs' choices, contrary to one of Open RAN's key goals.

3GPP refers to Open RAN interoperability as the ability of different RAN components to "interwork" through a standardized interface without requiring any proprietary interfaces or protocols [13]. The openness of the Open RAN components is a required specification, but it is insufficient to certify the equipment used in an Open RAN system.

Finally, the Global System for Mobile Communications (GSMA) industry association defines Open RAN interoperability as the ability of different RAN elements to work together seamlessly, regardless of the vendor or technology used [14].

All of these definitions have aspects of Open RAN interoperability that do not include transpiring nuances and statistical analysis required to rigorously understand the system's interoperability in different use cases and environmental conditions. As technology and industry evolve and new features are added, an additional definition is needed to help Open-RAN vendors verify their products against that and the users of the Open-RAN system to trust and satisfy the defines and procedure enough to use the comment in their commercial approach.

Before presenting our definition of interoperability in Section IV, let's look at the types of interoperability many entities refer to, sometimes unknowingly or implicitly.

A. Types of Interoperability

Taking a step back from the technical definitions we examined above, let us consider interoperability from a conceptual perspective. In any technical field, interoperability refers to the ability of systems, hardware, or software to communicate and exchange information effectively. Three main types may fit into this interoperability definition: syntactic, structural, and semantic.

Syntactic interoperability refers to the ability of two or more system components to exchange data or information using the same syntax or message format. The data must be structured consistently, using the same data format, protocol, or message structure. Syntactic interoperability is essential for systems to understand and process data correctly with the same format. Examples of syntactic interoperability include using the same protocol format for data exchange [15].

Structural interoperability refers to the ability of two or more system components to exchange data or information with the same meaning but different structures or representations. The data must be mapped or translated from one format to another to preserve the message. Structural interoperability is commonly used when we use different data models. Examples of structural interoperability would be within a node to translate the message to other layers of save the information in a separate database [15].

Semantic interoperability refers to the ability of nodes to exchange data or information with the same meaning and interpretation. It means that different systems must understand and interpret the data similarly. Semantic interoperability is essential for systems to exchange and use data effectively. Semantic interoperability includes standard vocabularies used within the system. For example, the signal-to-noise ratio (SNR) should have the same meaning in different entities [15].

We need to know when the interoperability mentions which type we are referencing. Sometimes, we may care about one aspect of interoperability; sometimes, we may mean all three types of interoperability. A truly interoperable system component should have all three interoperability components with the flexibility to innovate better software or hardware to perform their tasks.

Also, before defining true interoperability, we need to establish the definitions of some common vocabulary that could be used as a part of interoperability but are not. Some of their elements may overlap, but ultimately, they define another purpose. We must distinguish between Interoperability, Optimization, and Compliance, although an interoperable system has some aspects of optimized and compatible [16].

B. Interoperability, Optimization, and Compliance

In general, interoperability refers to the ability of the software and hardware of a system to work together seamlessly and efficiently, regardless of their manufacturing design and architecture. Strictly speaking, interoperability does *not* address other technical system aspects, including reliability, compatibility, adaptability, maintainability, or upgradability. A definition of interoperability may have elements of one or more of those concepts. However, even a rigorous definition and measurement method of interoperability should not replace a separate definition and analysis of the ability of a system to be maintained, upgraded, or adapted.

The concept and definition of interoperability also overlaps with the concepts of optimization and compliance. The relationship between interoperability and these two concepts is worth exploring in depth.

Optimization refers to improving system performance to make it more efficient or effective. This involves identifying the current state, defining a desired state, and finding ways to bridge the gap between the two by adjusting the hardware or tweaking the system parameters. In the context of an Open RAN system, optimization can refer to improving a system's or software's performance by making it have better use of the resources for a more tailored system for its use case, more stable, or less resource-intensive.

On the other hand, compliance refers to a set of rules or regulations. In the context of Open RAN, compliance often refers to meeting the O-RAN standards while meeting the desired key performance indicators (KPIs) [8].

Optimization, interoperability, and compliance are all important concepts that play different roles in the Open RAN system verification and should not be confused with each other while keeping in mind that, in some areas, they will overlap.

C. Interoperability in Practice: Plugfests

Having analyzed interoperability and similar terms conceptually and in the context of how Open RAN organizations currently define them, we turn our focus to interoperability in practice, specifically plugfests. How interoperability is currently measured and assessed in the Open-RAN community can illustrate challenges resulting from multiple and imprecise definitions.

Open RAN Plugfests are organized by a group of technology companies, telecommunications operators, and other organizations that advocate for developing and adopting open and interoperable Open RAN solutions, for example, the O-RAN alliance, TIP, or open networking foundation (ONF). The Plugfest is an opportunity for companies to quickly test and demonstrate the interoperability of their Open RAN solutions with other vendors' products, which helps to ensure that these solutions are compatible and can work together seamlessly in an Open RAN ecosystem. At an Open RAN Plugfest, companies can test various scenarios, including interoperability between vendors' hardware and software components, different Open RAN interfaces inter- and intra-RAN, and between Open RAN solutions and sometimes with the existing telecommunications networks. The event also provides a forum for companies to collaborate on developing new Open RAN features and specifications and share best practices for deploying and operating Open RAN networks [17]. Overall, the Open RAN Plugfest is essential in advancing the adoption of open and interoperable RAN solutions. However, in the long run, it hinders the scalability of coverage for all the various cases, scenarios, and vendors [18].

IV. RADIO UNIT INTEROPERABILITY

Focusing on the interoperability of the O-RU, we define its interoperability in the context of the larger Open-RAN ecosystem. After initial compatibility verification of the O-RU with the O-DU/L1, we examine the system parameters that affect the performance of the O-RU.

In this analysis, the O-RU is considered to be a black box. Once it has been confirmed that it is compatible with the O-DU/L1 and there is no issue with the fiber delay during the initial setup, the O-RU's performance can be managed through O-DU/L1 configurations, within its hardware limitation.

The process of creating a scientifically rigorous and quantifiable definition of O-RU has the following high-level steps:

1) Identify Key Performance Indicator(s) (KPI(s)) important for the application.
2) Consider all of the different system and environmental parameters that *might* impact the KPI(s) identified in the first step.
3) Design and execute a statistical factor screening experiment to determine which of the parameters in step two actually have an impact on the KPI(s).
4) With the subset of factors known to have an impact, design an efficient and practical test that can be used to quickly gauge interoperability.

For the analysis presented here, we focus on uplink and downlink throughput as our primary key performance indicators (KPIs). However the same analysis process could be repeated for other KPIs of interest (e.g., latency).

Step three - the factor screening experiment - is a necessary step because it helps identify factors that can be safely excluded from testing. This significantly reduces the size and scope of the final test method described in step four.

Overall, the process shown above should be generalizable to many (if not all) Open-RAN systems. That is, once the test is established in step four, it should be suitable for standardization and use across many platforms. The process above does not address the need for setting a threshold of acceptable performance to be considered "interoperable." Setting this threshold is outside the scope of this work, and is best addressed by the community.

A. Factor Selection and Screening

The process for this analysis follows a typical statistical factor screening experiment [19]. A factor screening experiment similar in design to this one was performed in [20] as part of an analysis on understanding the factors that influence the uplink power radiated from LTE user equipment.

Table. I shows the list of factors that could conceivably have an impact on throughput based on previous experiments [20] and 5G new radio (NR) throughput models. The selected factors are configurable and available with a common COTS Open-RAN system.

Several parameters can affect the performance of the O-RU with a handset, *RF interface*, or with an O-DU/L1 , *fiber evolved Common Public Radio Interface (eCPRI) interface*, for determining the interoperability of O-RU within the system. These parameters are the *delay and timing* between O-RU and O-DU/L1, the parameters that affect the *RF condition*, such as power control parameters, *environmental factors*, such as the type of traffic, the number of devices (*site loading*), and finally the *hardware factor*, i.e., CPU utilization, is considered. In the

TABLE I: List of Factor Screening Parameters

		Factor Values	
Factor Index	Factor Name	Low Value	High Value
A	Distance - Path loss (PL)	20 meters	500 meters
B	Downlink Traffic	Short Burst	Long Burst
C	Uplink Traffic	Short Burst	Long Burst
D	Timing Tx Windows	143 us	357 us
E	Timing Rx Windows	0 us	214 us
F	Channel BW	20 MHz	100 MHz
G	PUSCH p0Nominal	-94 dBm	-70 dBm
H	PUSCH Alpha	0.6	1
I	Downlink/Uplink slot ratio	1/3	3/1
G	Downlink QAM	64	256
K	Uplink QAM	64	256
L	Downlink MCS	0	31
M	Uplink MCS	0	28
N	Number of UEs	1	10
O	DU CPU utilization	50%	100%

next section, we see the effect of one set of these parameters on the downlink and uplink throughput of the system.

The design of experiments (DOE) involves varying the factors simultaneously to observe their individual and interactive effects on the response variable. Setting values for factors (high/low) is a crucial step in designing an experiment. The high and low levels should represent practical and meaningful extremes of the factor to understand the impact - if any - each of these factors has on the system throughput. We selected the low and high values of each factor based on their available values in a common COTS Open-RAN system, as long as they didn't impair the performance of the system as seen in Table. I.

B. A sample of data

In this section, we selected the common default parameters that are used in an Open RAN system as a sample to highlight the data required from a system to determine the interoperability of an O-RU in an Open RAN ecosystem. Fig.2 shows the downlink and uplink KPIs in the application and PDCP layers of an Open RAN 5G system. In this illustration. We collected this log from a real COTS Open RAN system with 100 MHz BW in the CBRS 3.5GHz band in the near-RF condition. As seen in Fig. 2, the throughput is normally adjusted for the downlink and uplink throughputs in both application and PDCP layers based on the bit error rate (BLER).

Fig.3 shows the latency and BLock Error Rate (BLER) of the same Open RAN system. The BLER stays zero through the test therefore no traffic adjustment were needed and the system stay stable. As seen in Fig.3, the delay was adjusted to a low value after its initial high value.

C. Impact of the RIC on Interoperability measurement

one of the significant advantages of the Open RAN is its new node, RIC, seen in Fig.4 in detail. RIC brings intelligence to
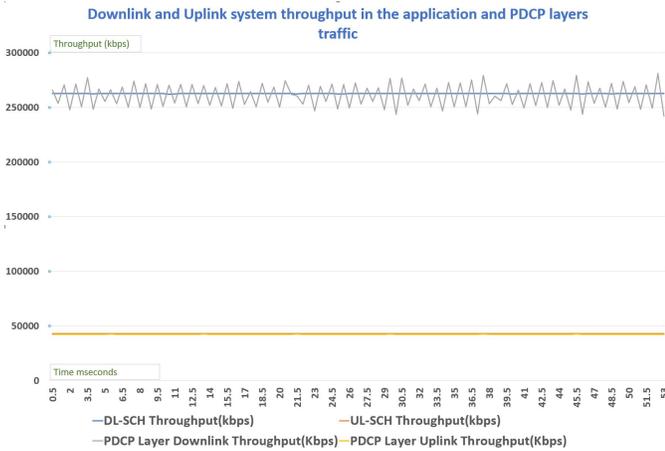
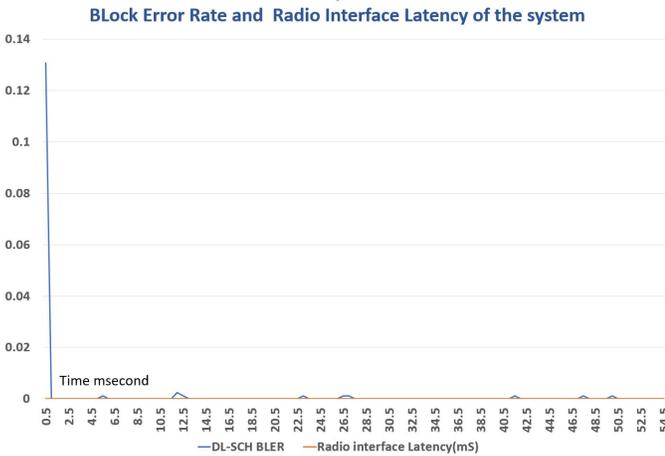Fig. 2: shows the Open RAN comparison between L3 and PDCP throughput for downlink and uplink.

Fig. 3: shows the delay and BLock Error RATE of our Open RAN system.

the Open RAN ecosystem. RIC provides a centralized and programmable interface to the RAN, enabling network operators to manage and automate network functions more efficiently and effectively. RIC can be developed with the general-purpose server and the host applications called xApp and rApp [21]. These two applications can tailor the operation of RAN based on the desired use case see Fig. 4. The data collected from RIC can also help to measure the interoperability of the system under test. It is possible to utilize the data gathered from the RIC to assess the system's interoperability faster even during normal operation in the field. The scope of adding RIC interoperability verification is beyond the scope of this paper and will be incorporated into our future Open RAN interoperability research.

V. Discussion and Future Work

Our proposed definition for Open RAN interoperability has some or all of the existing definitions without impeding the optimization, system cost, maintainability, stability, and security. Testing and reviewing these elements in various contexts and setups outside the scope of interoperability verification
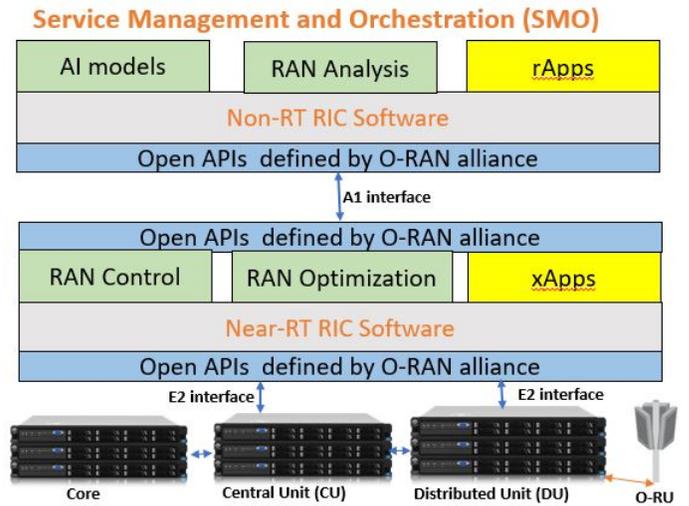

Fig. 4: RIC topology.

are essential. In upcoming work we will execute the factor screening experiment outlined in Section IV utilizing data from L1, L2, and L3 layers of different Open RAN nodes. After performing the factor screening experiment, we can review the impact of critical configuration factors affecting the system performance and finding the weight of each factor. With the weight of each factor determined, we can design a measurement method that quantify the interoperability of arbitrary O-RUs. This final test method will not be in the form of a factor screening test, as that only needs to be completed once for each set of KPIs. Rather the final test method will be similar to other standardized test methods.

This method has two advantages: it should be applicable across hardware and software vendors, and it is measurable and rigorous while utilizing a limited number of test cases. This approach to interoperability is not limited to the O-RU. The same process can be applied to the interoperability between the O-DU and O-CU.

VI. Conclusion

Interoperability is a crucial requirement of Open RAN, as it enables various components to communicate and work together effectively. Although the existing definition of the Open RAN, in addition to Plugfests have elements of interoperability verification, a comprehensive and measurable interoperability definition needs to measure interoperability scientifically and efficiently with a high degree of confidence. In this paper, we define interoperability testing as a minimum test suite in which the Open RAN system's elements and applications are tested in a controlled laboratory environment where actual commercial environment equipment with limited test suites are used to ensure that clarity of standards has been established and to detect potential discrepancies in addition to meeting KPIs. The factors in interoperability testing include the parameters available in each system element. The standard Open RAN interoperability testing methodology should follow a plan, do, check, and analysis cycles: Plan: determine the

functionality, behavior, input, and output for all components of the system from a pilot study and their definitions; Do: execute selected test cases based on factors selected from engineering judgment; Check results for consistency between each runs: revisit test results for system stability by verifying different RF indicators from independent sources; Analysis: Identify each parameter's estimated weight using static analysis or AI.

REFERENCES

[1] M. Liyanage, A. Braeken, S. Shahabuddin, and P. Ranaweera, "Open RAN security: Challenges and opportunities," *Journal of Network and Computer Applications,* 2023. 103621, ISSN 1084-8045. pp. 3–8.

[2] CTIA, "Wireless in 2022 More 5G Coverage, More Connections, and More Security", Available online: https://www.ctia.org/news/wireless-in-2022-more-5g-coverage-more-connections-and-more-security

[3] S. K. Singh, R. Singh and B. Kumbhani, "The Evolution of Radio Access Network Towards Open-RAN: Challenges and Opportunities," *2020 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, Seoul, Korea (South), 2020, pp. 1-6.

[4] D. Wypiór, M. Klinkowski, and I. Michalski, "Open RAN—Radio Access Network Evolution, Benefits and Market Trends," *Appl. Sci.* 2022, 12, 408.

[5] M. Liyanage, Madhusanka & Braeken, An & Shahabuddin, Shahriar & Ranaweera, Pasika. (2023). "Open RAN Security: Challenges and Opportunities". *Journal of Network and Computer Applications*.

[6] J. -C. Plantin (2021). "The geopolitical hijacking of open networking: the case of Open RAN," *European Journal of Communication*, 36(4), 404–417.

[7] M. Polese, L. Bonati, S. D'Oro, Stefano Basagni, Tommaso Melodia, "Understanding O-RAN: Architecture, Interfaces, Algorithms, Security, and Research Challenge", *IEEE Communications Surveys & Tutorials,* VOL. 25, NO. 2, SECOND QUARTER, 2023.

[8] O-RAN alliance, "Testing & Integration," Available online: https://www.o-ran.org/testing-integration. Accessed 7 Oct. 2023

[9] TIA, "Before the Federal Communications Commission Washington, DC 20230", Available online: https://tiaonline.org/wp-content/uploads/2021/05/2021.5.28-OpenRAN-NOI_Reply-Comments_Final.pdf pp. 3-5. Accessed 7 Oct. 2023

[10] ETSI, "Standardization vs. innovation vs. economization: The Open RAN balancing act", Available online: https://www.rcrwireless.com/20221104/open_ran/standardization-vs-innovation-vs-economization-the-open-ran-balancing/-act. Accessed 7 Oct. 2023

[11] SCF, "Small Cell Forum's specifications", Available online: https://www.scf.io/en/documents/050SmallcellsmarketforecastJuly2021.php. Accessed 7 Oct. 2023

[12] TIP, "TIP Badging', Available online: https://exchange.telecominfraproject.com/about-exchange/badges.. Accessed 7 Oct. 2023

[13] Moniem-Tech Mohamed Abdel Monem Available online: https://moniem-tech.com/2022/04/17/open-ran-interoperability-between-multi-vendor/. Accessed 7 Oct. 2023

[14] IEEE ComSoc "Ultra Oxymoron: GSMA teams up with O-RAN Alliance without liaison with 3GPP or ITU", Available online: https://techblog.comsoc.org/2020/05/30/ultra-oxymoron-gsma-teams-up-with-o-ran-alliance-without-liaison-with-3gpp-or-itu. Accessed 7 Oct. 2023

[15] J. Euzenat. "Towards a principled approach to semantic interoperability." *Proc. IJCAI 2001 workshop on ontology and information sharing,* Aug 2001, Seattle, United States. pp.19-25.

[16] N. Viet, "Open RAN Progressing on Network Interoperability and Performance with AI/ML,", white paper, Available online: https://www.businesswire.com/news/home/20230223005194/en/,February23,2023.. Accessed 7 Oct. 2023

[17] O-RAN Alliance, "O-RAN Minimum Viable Plan and Acceleration towards Commercialization," White Paper, 29 June 2021.

[18] K. Shakaki, "Open RAN What? Why? and Challenges,' Available online: https://www.linkedin.com/pulse/open-ran-what-why-challenges-khaled-shakaki/. Accessed 7 Oct. 2023

[19] Lutz, M. W., Menius, J. A., Choi, T. D., Gooding Laskody, R., Domanico, P. L., Goetz, A. S., Saussy, D. L. (1996). "Experimental design for high-throughput screening. Drug Discovery Today," 1(7), 277-286.

[20] J. Coder, A. Wunderlich, M. Frey, *et. al*, "Characterizing LTE User Equipment Emissions: Factor Screening", *NASCTN Report 7, NIST Technical Note* 2069, September 2019.

[21] P. H. Masur, J. H. Reed and N. K. Tripathi, "Artificial Intelligence in Open-Radio Access Network' in *IEEE Aerospace and Electronic Systems Magazine,* vol. 37, no. 9, pp. 6-15, 1 Sept. 2022