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Open RAN

An Interoperable, Innovative, and Sovereign Architecture

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Contents

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This paper is meant to be informative of the subject matter, from a technical, industrial, and regulatory perspectives, and it does not by any means represent the view or strategic plans of CST.

1. Executive Summary

Radio Access Networks (RANs) make up a major segment of the cellular network infrastructure. RANs have a large physical footprint, for every base station in the infrastructure has to be connected to a RAN [1]. They also claim a large portion of the Total Cost of Ownership (TCO) for cellular infrastructures, which is estimated by some reports—like [2] [3]—to be around 70%. Modern infrastructures have been characterized as being stagnant and sluggish [4] [2] [5]. This, to a large extent, is a consequence of how the RANs are usually developed, designed, and commissioned. A RAN is a full-stack all-in-one solution built using proprietary hardware and software components [6] [7] [8]. Introducing adjustments to a RAN requires the intervention of the vendor who supplies it, let alone customizing and modifying the whole stack or part of it. Such requirement renders the owners of the telecommunication infrastructure locked-in to certain vendors. To add insult to injury, the monolithic nature of RAN makes its development and large-scale production limited to a certain number of vendors. This diminishes the level of competition in the market, which takes a toll on the CAPtital and OPerational EXpendiures (CAPEX and OPEX) of the infrastructure owners. The increased costs and limited competition also impact innovation in the telecommunication industry; introducing new services or supporting new technologies is expensive in today's markets.

Open RAN and Its Stakeholders

Re-envisioning the RAN architecture is key to facing the issues plaguing the telecommunication infrastructure, and this is what the Open Radio Access Network (Open RAN) architecture is aimed to do. Open RAN could be viewed as a move to transform the RAN to a cloud-like elastic, adaptable, and agile segment of the infrastructure [2], one that is easily expanded and customized to meet demands as well as hospitable to novel services and emerging technologies. The pillars of such transformation are the four principles of Open RAN, which are [4]: (i) disaggregating the RAN into modular components; (ii) virtualizing many RAN functionalities to decouple software from hardware; (iii) defining open interfaces between RAN components to support interoperability; and finally (iv) embracing Artificial Intelligence (AI) and Machine Learning (ML) to enable data-driven control and adaptability.

Although Open RAN started as a movement led by Mobile Network Operators (MNOs), it has a diverse set of stakeholders who are interested in realizing its various benefits. Those stakeholders could be clustered into four broad categories: (i) legislators and policy-makers, (ii) service and infrastructure providers, (iii) vendors and integrators, and (iv) research and development institutes. All fours are interested in realizing one or multiple benefits that are brough about by the architecture. They are driven to do so by different motives that are a combination of three fundamental values: (i) improving finances, (ii) inspiring innovation, and (iii) bolstering infrastructure sovereignty. Table 1 connects the main benefits of Open RAN with interested stakeholder categories and

what motivates them to be interested.

Global Momentum and Market Outlook

The interest in Open RAN has been building up for a while in the telecommunication industry, and it has only begun to materialize into actual steps in the past few years. Several operator-led and vendor-led alliances have been formed to: (i) set up standards for Open RAN architecture, (ii) encourage research and development for Open RAN software and hardware components, and (ii) enable the development, testing, and deployment of Open RAN solutions. Good examples are the O-RAN alliance and the

Table 1: Summarizing Open RAN benefits, who is interested in them, and the motives behind the interests.

		Categories of stakeholder			
		Legislators and policy-makers	**Service and infrastructure providers**	**Vendors and integrators**	**Research and development institutes**
Open RAN Benefits	**Supply-chain diversity**	Encourage local vendors and increase data and equipment security	Reduce CAPEX and OPEX	Achieve interoperability between different vendor equipment	
	Value-chain and revenue diversity		Generate new streams of revenue	Boost revenues and market share	
	Innovation in telecommunications	Enrich the telecom local market with services, and to influence global markets		Produce competitive equipment and solutions	Develop novel technologies and solutions
	Resilient infrastructure and markets	Reduce the impact of supply-chain disruptions on infrastructure and markets alike	Maintain stable and prosperous business		Cultivate and localize know-how and skillsets

Improving finances Inspiring innovation Bolstering infrastructure sovereignty

Telecom Infra Project (TIP), which are, respectively, focused on the development of Open RAN standards and the testing and deployment of Open RAN solutions. Complementary to those efforts is the work of legislators and policy-makers. Their contributions, in general, fall under the umbrella of supporting research and development, and they do so in a direct and indirect manners. The direct support sees funds go to research focused on developing and deploying Open RAN solutions. A good example is the establishment of SONIC labs in the UK by Ofcom and Digital Catapult [9]. The indirect support, on the other hand, funnels funds toward advance research and innovation in telecommunications in general. A good example is the designation of telecommunication innovation zones by the USA FCC [10].

Despite the global momentum, Open RAN is surrounded with controversy that is rooted in its market potential. The dominant question nowadays is whether Open RAN can actually deliver on its promised benefits or not. Thus, some effort has been devoted to project the revenue and market share of Open RAN as well as estimating its expected savings. A study from ABI Research [11] expects Open RAN to dominate the market in the year 2028 onwards, and the study also projects Open RAN revenue to sustain a Cumulative Annual Growth Rate (CAGR) of 30% between the years of 2021 and 2030, growing from USD 2 billion to USD 30 billion. Other studies from AGC Research [3] and Analysys Mason [12] focus on estimating the TCO savings of Open RAN compared to traditional RAN—they both utilize proprietary TCO models. The former reports between 18% to 35% TCO saving for greenfield deployments while the latter expects a 30% TCO saving for brownfield deployments.

Open RAN Efforts and Potential in the Kingdom

The momentum of Open RAN is rippling through the world and reaching the Kingdom of Saudi Arabia. Major MNOs have been engaged with leading Open RAN vendors and alliances to trial Open RANs for brownfield deployments [13], establish regional labs [14], and contribute to standardization efforts [15]. The government, represented by the Ministry of Communications and Information Technology (MCIT), is also joining the local momentum; it has signed a Memorandum of Cooperation (MoC) with its USA counterpart to collaborate on advance telecommunication research and development, including Open RAN [16]. All the aforementioned efforts are expected to deliver multiple benefits to the telecommunication industry in the Kingdom, which are summarized in the following two points: (i) leveling the playing field and encouraging the emergence of local vendors, and (ii) cultivating local know-hows and skillsets.

2. Introduction

A cellular wireless network can be generally decomposed into two major components, which are Radio Access Network (RAN) and Mobile Core [1]. The former is responsible for managing the radio resources of the cellular network in a single or multiple geographical locations (called base station sites). It makes sure that end-users (or user equipment in other words) are connected to the cellular network and are receiving the quality of service (QoS) their running applications demand. The Mobile Core, on the other hand, is a network composed of a suite of functionalities that does the following: (i) provide connectivity to the Internet for data and voice services, (ii) ensure that the Internet connectivity maintains the promised QoS, (iii) ensure uninterrupted service for both moving and stationary end-users, and, finally, (iv) track usage of subscribers for billing and charging purposes.

A. Traditional RAN

RANs are commonly developed, designed, and commissioned as a full-stack one-box solution to Mobile Network Operators (MNOs) [4] [8] [6] [17]. This is referred to in this report as the traditional RAN design approach, or simply traditional RAN. Mobile network equipment vendors (simply termed equipment vendors henceforth) are responsible for designing the whole stack, and in doing so, they produce RAN solutions that uphold the following qualities:

i. Meet, and in some times, exceed the 3GPP standards as well as the requirements of MNOs.

ii. Produce reliable and robust systems in terms of performance.

iii. Provide easily maintained systems with quick troubleshooting.

All the above qualities are admirable properties for traditional RANs; they provide peace of mind to MNOs and infrastructure owners regarding the performance of their networks. They also contribute to reducing any downtime, for the whole solution is usually well-tested and sourced from one vendor.

Equipment vendors commonly resort to designing proprietary hardware and software components to meet the three qualities. Hence, the whole RAN is viewed as a black box by operators; introducing architectural and functional changes demands intervention from the vendor who supplied the RAN, which gives raise to the notion of getting "locked-in" to a certain vendor. Vendor lock-in might not seem like a big deal if it has not been for the limited number of vendors available [5] [7] [18]. The reality of today's market is that it is composed of a small number of RAN stack developers and manufacturers. This could be attributed in large part to the high entry barrier, which is, in simple terms, the difficulty of producing full-stack custom-made RANs at large scale [7] [19]; the

process has traditionally involved the design and integration of various components, ranging from radio antennas and mixers to specialized digital signal processing units and their software.

B. Challenges and the Need for a Solution

Together with the vendor lock-in, limited choices have rendered the RAN side of the telecommunication infrastructure stagnant and sluggish for a long time [2] [5] [4]. Expanding to new markets requires large CAPital EXpenditure (CAPEX) and piles on OPerating EXpenditure (OPEX). It is estimated that 70% of the Total Cost of Ownership (TCO) in the telecommunication infrastructure is localized within the RAN side [3] [2]. This gets operators to think twice before any expansion or even any offering of new services. The expenses also generate a rippling effect that extends beyond the expansion to new markets or services. It hinders innovation [5]; research and development require an elastic and almost borderless environment, where ideas could be developed, tested, and demonstrated with as little restrictions as possible. Bringing inventions to life (i.e., rolling out a new technology, service... etc.) requires lean and agile infrastructure. All that is not supported with current RANs and their architectures.

The telecommunication industry is due for a transformative change in its RAN infrastructure, one that brings cloud-like elasticity, agility, and economics to the industry [2]. It should allow vendor diversity, embrace scale-out and scale-up mentalities, and inspire innovation. One way to attain a transformation like that is by adopting the Open Radio Access Network (Open RAN) architecture. The architecture is inspired by the current needs of the industry and is envisioned as a means to change its dynamics. It is supported by many major MNOs and embraced by many equipment vendors [15]. The architecture represents a huge deviation from the current norm towards a situation where RANs are designed using disaggregated, virtualized, and interoperable components and with Artificial Intelligence (AI) built right into it (native-AI design).

Whether the conditions are right or not for Open RAN is a lingering question in today's telecommunication atmosphere. A transformation like that brought on by Open RAN may seem a bit far-fetched in the wrong market climate, for the architecture could be characterized as ecosystem-disruptive. Many, however, argue that the telecommunication industry is currently ripe for such transformation; the 5th generation (5G) cellular technology is being rolled out, and with it comes growing demands to densify the cellular network and meet varying requirements. The densification is a technical consequence of the technology evolution[1] while the varying requirements are introduced by the wide consumer base of 5G (e.g., individuals, manufacturing, healthcare, etc.). The deployment of 5G networks could be the right entry point for a disruptive architectural change like that of Open RAN.

1. Densifying cellular networks means deploying more base stations with small coverage areas. It is a means to achieve better coverage and quality of service. Dense cell deployment enables the use of millimeter Wave (mmWave) frequency and improve area spectral efficiency—see [53] to learn more.

C. Scope of Paper

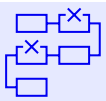
This paper aims to provide a concise account on Open RAN for a wide spectrum of audience. It explores the Open RAN architecture and its design principles, which it subsequently utilizes to derive the most celebrated benefits of the architecture. Those benefits are complemented by a discussion on the pool of stakeholders with vested interest in Open RAN. In particular, the paper proposes a categorization of stakeholders and analyzes their drives. It presents its analysis in the form of a novel indicator termed the "stake-space indicator." Understanding the architecture and its stakeholders sets up the stage for a discussion on the global landscape of Open RAN as it stands today, with an eye on its future. The discussion explores the most prominent steps taken by stakeholders to realize the benefits of Open RAN, which includes market projections and regulatory and policy-making efforts. The ripples of those steps extend to impact the Saudi Arabian telecommunication industry, and as such, the shaping local landscape of Open RAN is overviewed at the end of this paper.

3. What Is Open RAN?

This question is a good way to kick off the discussion in this paper. Answering it lays the foundation for those who are not familiar with the architecture and serves as a refresher for the experienced ones.

A. Architecture Description

Open RAN is a movement that aims to re-envision the RAN architecture and operation [15] [20]. It is launched by different alliances of MNOs and has been expanding to include equipment vendors, academia, legislators, and policy-makers. The new vision has the RAN architecture disaggregated into several functional units with focus on three principles in addition to disaggregation, which are virtualization, intelligent control, and open interfaces [4]



Disaggregation breaks the RAN stack into functional units (hardware and software). This principle lays the foundation for modularity in the RAN. It also opens doors for flexible and light-weight deployment that support simplified cell-site and embrace the ability to scale-out[2].

Virtualization guarantees the decoupling of the RAN hardware and software such that some of the functional units are deployed using general-purpose hardware. It also helps transition the RAN to a software-defined platform.

Intelligent control means the RAN could run Artificial Intelligence (AI) and Machine Learning (ML) algorithms that optimize its operation and help deliver advance services.

Open interfaces are the manifestation of modularity in the Open RAN architecture. They are the means to get the functional units of the Open RAN talking to each other and exchanging data regardless of who developed those units.

Disaggregation and the other three principles collectively enable an unprecedented level of flexibility in cellular service provision and network adaptation, a level that could not be reached with traditional all-in-one RANs. MNO could run various RAN configurations in their network, and thanks to intelligent control and virtualization, those configurations could be adjusted based on the demand at certain base station sites.

2. Scale out in this paper refers to the consolidation of system resource to improve processing, storage, or networking capacities. It is different from scaling up which focuses on upgrading equipment to achieve higher capacity.

That flexibility afforded by Open RAN is augmented with the fact that the architecture embraces the 3GPP functional disaggregation paradigm. Such paradigm allows flexible RAN deployment scenarios [4]—more on that could be found in the 3GPP technical specification report in [21]. However, unlike Open RAN, it does not go beyond functional disaggregation; the RAN is still regarded as an all-in-one solution provided by a single vendor. This gives the edge to the Open RAN architecture which disaggregates functionalities and enhances them with the principles of virtualization, intelligent control, and open interfaces. Open RAN does all that while proclaiming its 3GPP compatibility. Figure 1 shows an illustration of an Open RAN architecture in comparison to a 3GPP "traditional" RAN architecture. Both architectures are designed following the 3GPP gNB 7.2x split, which is a popular functional disaggregation scenario.

B. Benefits of Open RAN

The Open RAN architecture, described in Section III.A, is touted as the source of an array of benefits to the telecommunication industry [8] [22]. It is envisioned as a way to revitalize the monolithic and stagnant cellular infrastructure, speed up time-to-market for new services, and improve finances of MNOs and infrastructure owners [11] [5] [23]. The benefits of Open RAN could be discussed along four directions, all of which are rooted in the architectural principles of Open RAN.

Supply-chain diversity: Disaggregating and virtualizing RAN components along with standardizing open interfaces among those components are a means to allowing interoperability within the RAN stack. This means different vendors could develop different components of the RAN, and this creates a supply-chain diversity for MNOs and infrastructure owners [17] [11]. Such diversity is vital for reducing costs (especially CAPEX) and stimulating competitiveness and innovation. It also could help speed up upgrades or tweaks to parts or all of the infrastructure. This is critical to service provision and meeting the demands of customers. Traditional RAN architectures do not enjoy that diversity; all RAN components are sourced from the same vendor, and replacing a component with another from a different vendor is extremely difficult if not impossible. This has hindered competition in the RAN market as a vendor needs to develop a full stack to have a feasible business model.

Innovation in telecommunications: Open RAN could give raise to innovation on different levels of the telecommunication infrastructure, whether on the level of developing the infrastructure itself, the services it provides, or its use cases [17] [2]. A fundamental outcome that derives directly from supply-chain diversity is the increased level of competition, which when given the right conditions, drives up innovation [5]. Disaggregation and virtualization when coupled with intelligent control in the architecture could also be catalysts of innovation. They provide developers and researchers easy access to a hospitable and accommodating environment where ideas can be tested. They also allow them to test new deployment scenarios and identify new use cases.

Value-chain and revenue diversity: Creating a multi-vendor ecosystem for developing and deploying RANs is a source of another diversity in the telecommunication industry, value-chain and revenue diversity. Having standardized and disaggregated RANs with open interfaces inspires infrastructure owners and MNOs to find new

ways of generating revenues and embrace cloud-scale economics at the RAN side [2]. They could directly capitalize on the reduced capital costs that result from the supply-chain diversity to improve their revenue margins. Those savings pave the way for coverage expansions to areas that are usually hard to reach or too expensive to cover. MNOs could also derive new streams of revenue by adapting certain parts of their network to the needs of consumers served by those parts. For instance, virtualization and intelligent control could enable MNOs to customize a private network for a customer on demand and over a specific term [11].

Resilient infrastructure and market: The ability to mix-and-match components from various vendors means that players in the telecommunication industry could not get locked-in to a certain vendor, which makes their infrastructure resilient to any disruptions in the supply chain or turbulence in the geopolitical atmosphere [24] [25] [7]. This is something that Open RAN promises to enable with its architectural principles and supply-chain diversity. Open RAN even goes beyond that to bolster local markets with talented individuals and local vendors. It could lower the entry barrier for startups and small enterprises that would like to enter the market, for those new entrants are not required to shoulder the burden of developing full and competitive RAN solutions. Instead, they could just focus on delivering competitive hardware or software components.

Legend

CPRI: Common Public Radio Interface, **MAC:** Medium Access Control, **RLC:** Radio Link Control, **SDAP:** Service Data Adaptation Protocol, **PDCP:** Packet Data Convergence Protocol, **RRC:** Radio Resource Control

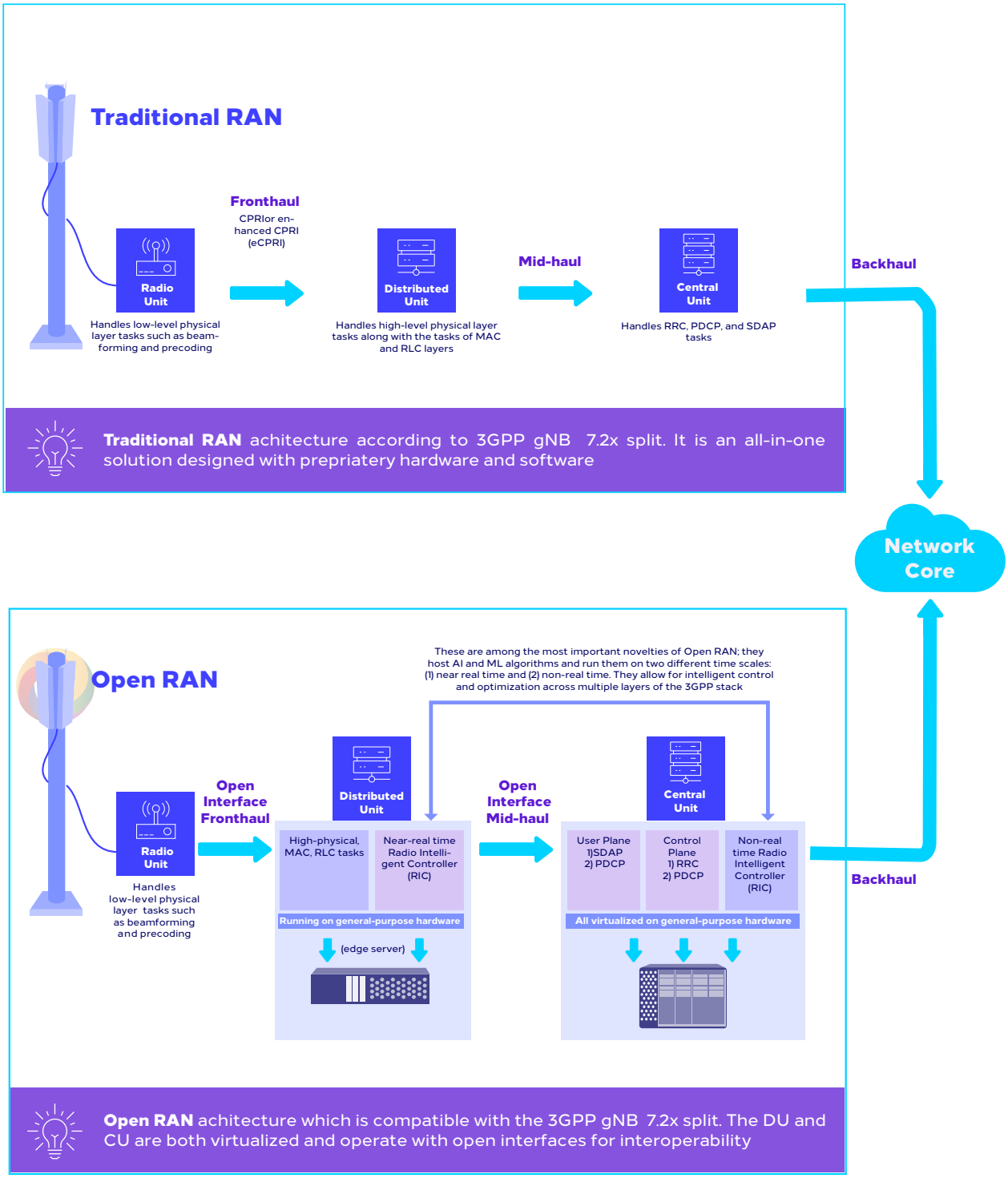
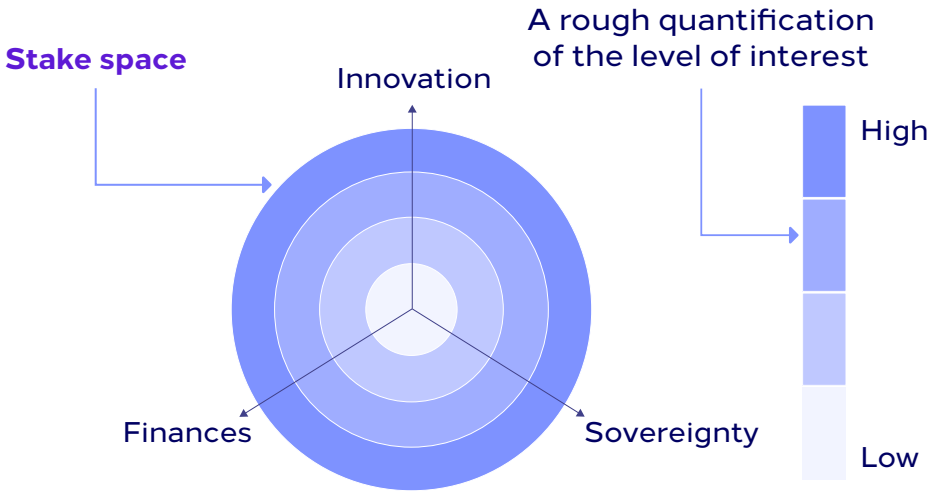


Figure 1: Illustration of Open RAN with a comparise to traditional RAN. Both architec-tures are designed following the 3GPP gNB 7.2x split.

4. Open RAN Stakeholders and Motives to Embrace the Architecture

Cellular services are constantly evolving to meet the demands of current and emerging technologies [26] [2]. Autonomous vehicles, for instance, have very different service requirement than legacy video streaming services; they represent an example of mission-critical technologies that require ultra-reliable and low-latency service and not enhanced mobile broadband service required by data-hungry technologies, of which video streaming is a good example. With such evolution usually comes an inflating burden on MNOs to meet the demands. Shouldering that burden means upgrading and, in some cases, expanding cellular infrastructure, something that is usually accompanied with large expenditures [2]. The Open RAN architecture represents a promising way to tackle the expenditure challenge and meet the demands [2] [4].

What is interesting about Open RAN is that although it started as an operator-led alliance with a somewhat business-oriented drive [2], it has a diverse pool of interested entities (henceforth called stakeholder pool) with different drives that go beyond just alleviating the expenditure challenge [5]. Regulators, policy-makers, lawmakers, research and development (R&D) institutes, telecommunication hardware and software vendors, among others, are all Open RAN stakeholders who share interest with MNOs in the architecture [15] [24] [5]. The stakeholder pool in general could be divided into four categories based on the functional scope of the stakeholders. These categories are: (i) legislators and policy-makers, (ii) service and infrastructure providers, (iii) vendors and integrators, and (iv) R&D institutes. Each of these categories is composed of a homogeneous set of stakeholders that shares similar motivation for embracing the Open RAN architecture.



Innovation

A short for "inspiring innovation," which refers to evolving the cellular infrastructure into a hospitable environment for new services as well as emerging technologies.

Finances

A short for "improved finances," which refers to the desire of some stakeholders to reduce expenditure and generate new streams of revenue.

Sovereignty

A short for "bolstered infrastructure sovereignty," which refers to the localization of telecommunications know-how and skills as well as securing the infrastructure and the data flowing through it.

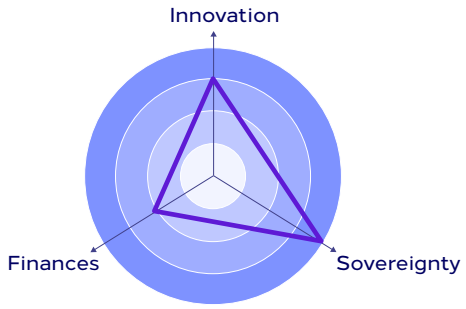
Figure 2: The structure of stake space and definitions of its dimensions.

Open RAN stakeholders across categories may appear to have different motives for their interests, at least on the surface; however, a closer look at those motives might reveal an intriguing pattern. They could be viewed as a combination of three fundamental values that Open RAN can attain, which are: (i) improved finances, (ii) inspiring innovation, and (iii) bolstered infrastructure sovereignty. The three values envelop most of, if not all, the reasons that have been put forth by Open RAN stakeholders to explain their embrace of the architecture. Improving finances reflects the desire of some stakeholders to reduce expenditure and generate new streams of revenue. It is the main drive for those interested in realizing the first and third benefits of Open RAN, namely supply-chain diversity and value-chain and revenue diversity, see Section III.B. The second value, inspiring innovation, embodies the drive of some stakeholders who are seeking to evolve the cellular infrastructure into a hospitable environment for new services as well as emerging technologies. Such evolution helps those stakeholders realize the second and third benefits of Open RAN, which are innovation in telecommunications and value-chain and revenue diversity. The third value, bolstering infrastructure sovereignty, is a manifestation of some stakeholders' desire to localize the telecommunications know-how and skills as well as secure the infrastructure and the data flowing through it. This is instrumental to develop a resilient infrastructure and prosperous markets, which is the fourth benefit of Open RAN. In a comprehensive view, the three values could be seen as the dimensions of a space that envelops the motives of all stakeholders. This space will be henceforth referred to as the stake space, which

is illustrated in Figure 2. Assigning different weights to the three dimensions and combining them generates the stake indicator of a certain stakeholder or category of stakeholders[3].

The following few subsections will further explore the stakeholder categories and their motivations. They aim to provide a clear but informal definition of each category and discuss the motives of each one. The discussion will be developed around the stake space and will provide a unique stake indicator for each category. The section will be wrapped up in a remark exploring the intersection of Open RAN benefits and stakeholder categories.

A. Legislators and Policy-makers



All organizations invested in crafting policies and passing legislations that regulate and organize the telecommunication industry and its various markets in a country or a union of countries.

Fostering innovation across the telecommunication industry and markets.

Securing the infrastructure and its sovereignty.

Figure 3: A visualization of Open RAN stake indicator for legislators and policy-makers.

The name of this category is somewhat self-explanatory; it combines all organizations that are invested in crafting policies and passing legislations that, in turn, regulate and organize the telecommunication industry and its various markets in a country or a union of countries. The USA's Federal Communication Commission (FCC), the UK's Office of communications (better known as Ofcom), and Saudi Arabia's Communications, Space, and Technology Commission (CST) are all good examples for organizations that fall in that category of stakeholders. Given their legistative and executive nature, the stakeholders here are invested in Open RAN for a myriad of reasons that revolve around two major dimensions (or values), innovation and security [24] [5] [27] [28].

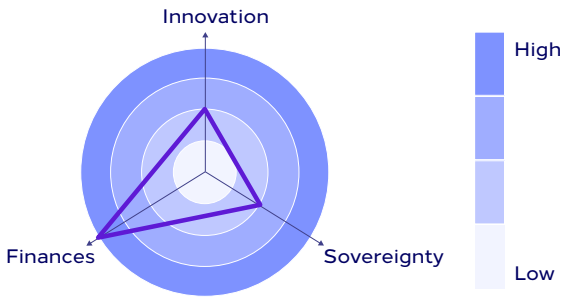
Although laws and policies are meant to regulate the telecommunication industry and markets, the main interest of organizations in this category is not on driving down expenditure for MNOs but rather on fostering innovation and securing the telecommunication infrastructure and its sovereignty. Open RAN pushes the telecommunication infrastructure towards becoming a diversified industry. This means an industry with a diverse RAN supply chain where multiple vendors (software and

3. Please note that the stake indicator is a subjective metric that is meant to reflect how different the interests of stakeholder categories are. It should not be used to benchmark or quantitatively compare stakeholders.

hardware alike) aim to produce best possible RAN components [11]. It also lowers what is referred to as the entry barrier for new players in the market, especially vendors. This altogether translates into a lively competition which could be argued to promote innovation as put forth in an Ofcom 2021 report [5], among others. Innovation in general has two desirable outcomes. The first is direct, which is enriching the telecommunication market with new services and emerging technologies. The second, on the other hand, is indirect and concerns the role a country or a union plays in influencing global telecommunication markets. Both outcomes are of interest to legislators and policy-makers, and both could be made possible by Open RAN.

In addition to innovation, legislators and policy- makers have a keen eye on security and sovereignty of the infrastructure [11]; having a small number of vendors who dominate the industry leads to concerns about operator lock-in. In other words, they are concerned about two things: (i) how much control operators have on their own infrastructures, which makes up a big chunk of a country's or a union's whole telecommunication infrastructure.; and (ii) to what extent the infrastructure can protect the privacy of the user data flowing through it. Open RAN represents a movement that grants operators, or more specifically infrastructure owners, more control over their RANs. It also lowers the entry barrier for local business to contribute to the infrastructure (i.e., consolidating its sovereignty). When it comes to data privacy, the control Open RAN offers to infrastructure owners and operators has the potential to provide better security than that offered by the pervasive block-box traditional RAN architecture. However, some might argue that the open nature of the interfaces in Open RAN could lead to data exposure, which actually increases the security risks. Hence, one could conclude that the jury is still out on how much data security Open RAN could provide. Figure 3 depicts the stake indicator of legislators and policy-makers and summarizes the discussion of this subsection.

B. Service and Infrastructure Providers



MNOs are the providers of cellular services to the end users.

Neutral hosts are telecommunication infrastructure providers, who do not provide services to end-users, Lowering CAPEX and OPEX

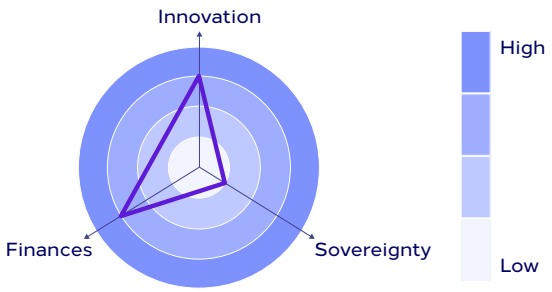
Generating new streams of revenue through the offering of innovative services.

Figure 4: A visualization of Open RAN stake indicator for service and infrastructure providers.

This category represents the main beneficiaries and founders of the Open RAN movement [15]. MNOs are the providers of cellular services to the end users such as voice calls, data, and SMS. They typically undertake the jobs of planning and deploying the cellular network as well as operating that network. Therefore, they feel the financial pressure that comes with those jobs and with the need to meet the demands of the cellular market. The composition of this category has another type of stakeholders, which are the so-called neutral hosts. They are essentially telecommunication infrastructure providers [29], and their business model is inspired by a cloud computing delivery model called Infrastructure-as-a-Service (IaaS) [30]. Neutral hosts commonly do not provide services to end-users, only infrastructure to MNOs.

The interest of both MNOs and neutral hosts in the Open RAN architecture have deep financial roots. As the leaders of the Open RAN movement, the interests of MNOs in the architecture have long been made clear; they aim to drive down CAPital EXpenditure (CAPEX) and OPerational EXpenditure (OPEX). RANs are known to bite off a big chunk of the infrastructure deployment and operation bill [31]. ACG Research has put that chunk in context by estimating that RANs represent 70-80% of the Total Cost of Ownership (TOC) of a cellular network. Therefore, RANs make great targets to improve finances by reducing expenditure. Such reduction could be achieved through the adoption of a "mix-and-match" approach to designing the RAN instead of the traditional vendor-locked approach. The new approach is made possible by the diversification of the RAN supply-chain, which is an essential characteristic of the Open RAN architecture [11]. MNOs are also interested in generating new streams of revenue through innovative services [5]. This is made possible by the flexibility (i.e., reconfigurability) the Open RAN architecture offers through virtualization, software-defined functionalities, intelligent control and open interfaces. Not different from MNOs are the neutral hosts; they are interested in Open RAN to drive down CAPEX and OPEX and bolster revenues. However, they may not be as invested in generating new revenue streams through innovative services as their MNO counterparts. Figure 4 depicts the stake indicator of this category and summarizes the discussion of this subsection.

C. Vendors and Integrators



Integrators take on the task of building the RAN stack while vendors develop and manufacture Open RAN components and could also integrate full Open RAN stacks.

Develop innovative features and services with accelerated time-to-market.

Expand RAN ecosystem with new vendors, solution integrators, and system integrators, leading to diversified value-chains.

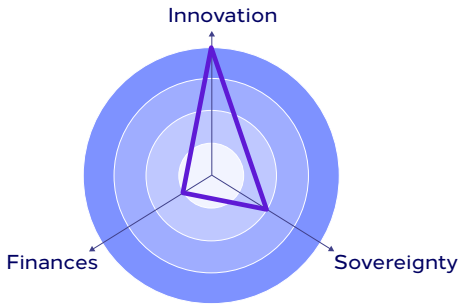
Figure 5: A visualization of Open RAN stake indicator for vendors and integrators.

The third category of stakeholders encompasses the business partners of service and infrastructure providers (i.e., MNOs and neutral hosts), which are the equipment vendors and system integrators. They are typically the suppliers of RANs and their software. They are commonly responsible for developing RAN stacks that meet or exceed the 3GPP standards and service and infrastructure providers' requirements. In the realm of Open RAN, vendors and integrators could be viewed as both protagonists and antagonists; this is because the essence of Open RAN stems from the need to avoid vendor lock-in [2] [4] [17]. This casts the stakeholders of this category in the role of the antagonists that the MNOs are, figuratively, fighting. On the other hand, they are also cast in the role of the protagonists; two of the major benefits unlocked by Open RAN are supply chain and value-chain diversities [8] [11], both of which cannot be achieved without the direct involvement and embrace of vendors and integrators to the Open RAN movement.

With their somewhat conflicting roles, one might wonder whether vendors and integrators could actually be considered stakeholders in the Open RAN movement or not. The simple answer is yes, they are, and they are actually major stakeholders; they are the ones that bring the concept of Open RAN to life. They are, however, split around Open RAN into two camps, the cautious and the enthusiast. The former camp could be seen as the club of contemporarily dominant and well-known vendors such as Ericsson and Huawei [32] [33]. They do not oppose the concept of Open RAN per se, but rather, they preach cautious in how it is approached. This is evident, for example, in Ericsson's letter to the US Federal Communication Commission (FCC) on the matter of Promoting the Deployment of 5G Open Radio Access Networks [32]. They point out a few issues with Open RAN standard development (for which they are actively contributing) and urge FCC to stay unbiased. The second camp, on the other hand, comprises diverse constituents, from small and medium telecommunication enterprises (e.g., Altiostar and Mavenir) to large enterprises (e.g., Samsung and Fujitsu). They are public supporters of Open RAN [34] [35] [8], and they are actively engaged in the development of its standards as well as in the deployments of the architecture with MNOs.

Despite of the different views on Open RAN among vendors and integrators, they share similar drives for their interest in the architecture, i.e., have a similar stake indicator which is depicted in Figure 5. They are invested in the architecture as it opens doors for competitive innovation [7]. Open RAN embraces virtualization, AI, and implicitly software-defined functionalities. All are means to introduce new features to the telecommunication infrastructure and new services to the end users. Innovation in Open RAN is also expected to be the bedrock for new roles in the telecommunication industry. For instance, it inspires the role of a solution integrator [17]. This role extends beyond the need to integrate Open RAN components and insure their interoperability. It taps into the open-interfaces, virtualization, and native-AI capabilities of Open RAN to define a type of integrators that orchestrates end-to-end services throughout the telecommunication infrastructure, i.e., from user equipment to mobile core. Putting the new features, services, and roles together shows the financial promise of Open RAN. They collectively could help bring in new streams of revenue and improve finances, which is the second principle dimension of the category's stake indicator.

D. R&D Institutes



Research centers and groups in the public or private sectors, commonly hosted in universities, institutes, organizations, or companies

Tap into the openness of O-RAN to test and demo novel ideas and solutions.

Cultivate skills and know-how to secure the sovereignty of the telecommunication infrastructure.

Figure 6: A visualization of Open RAN stake indicator for R&D institutes.

The fourth and last category of stakeholders encompasses research centers and groups in the public or private sectors. They are commonly hosted in universities, institutes, organizations, or companies. They are research focused with the aim to develop novel solutions, be they core telecommunication solutions or emerging use-cases or technologies enabled by the telecommunication infrastructure.

The nature of these stakeholders makes them at the forefront of innovation, skill development, and experience cultivation, which defines their interest in Open RAN. It has long been known that obtaining realistic data or assembling testbeds to address core telecommunication problems or test novel ideas enabled by telecommunications is quite difficult and costly [36]. Part of that difficulty comes from the complexity of the cellular network, a monolithic network of thousands of connected devices, base stations, and sub-networks. The other part is a result of the fact that majority of the network equipment and software are proprietary and hard to access, especially in the RAN side of the network. These reasons are driving the interest in Open RAN among the stakeholders of this category; open interfaces, modular architecture, software-defined functionalities, intelligent control, and virtualization all promise a flexible infrastructure which could be very accommodating for new ideas and solutions. They also suggest that slices of the infrastructure (e.g., the physical layer of the RAN or the whole RAN stack) could be built as laboratory testbeds to facilitate data collection, solution development, and solution testing. Hosting and enabling such innovative environments mean that R&D institutes are able to foster individuals' skillset and cultivate telecommunication and IT expertise. This is important from a national perspective, for it gives those institutes an indirect role in securing the telecommunication infrastructure and its sovereignty. Figure 6 depicts the stake indicator of the category and summarizes discussion of the subsection.

Remark on the Realization Matrix of Open RAN Benefits

The four categories of stakeholders are not operating independently from the major benefits Open RAN is promising (which are summarized in Section III.B). Their motives to embrace the architecture service the target of realizing some or all benefits associated with Open RAN. As such, one could think of their stake indicators as the average of their interests across all the benefits they hope to realize. Figure 7 depicts a lattice that illustrates the relation between: (i) Open RAN benefits, (ii) stakeholder categories, and (iii) fundamental values (i.e., stake space dimensions). This lattice is referred to as the "realization matrix," for it shows which benefit is of interest to a stakeholder and what motivates a stakeholder to seek the realization of that benefit. More specifically, each intersection in the figure depicts a benefit-specific stake indicator quantifying the motivation of a category in realizing a benefit, and averaging out indicators across benefits results in the overall stake indicator of a category.

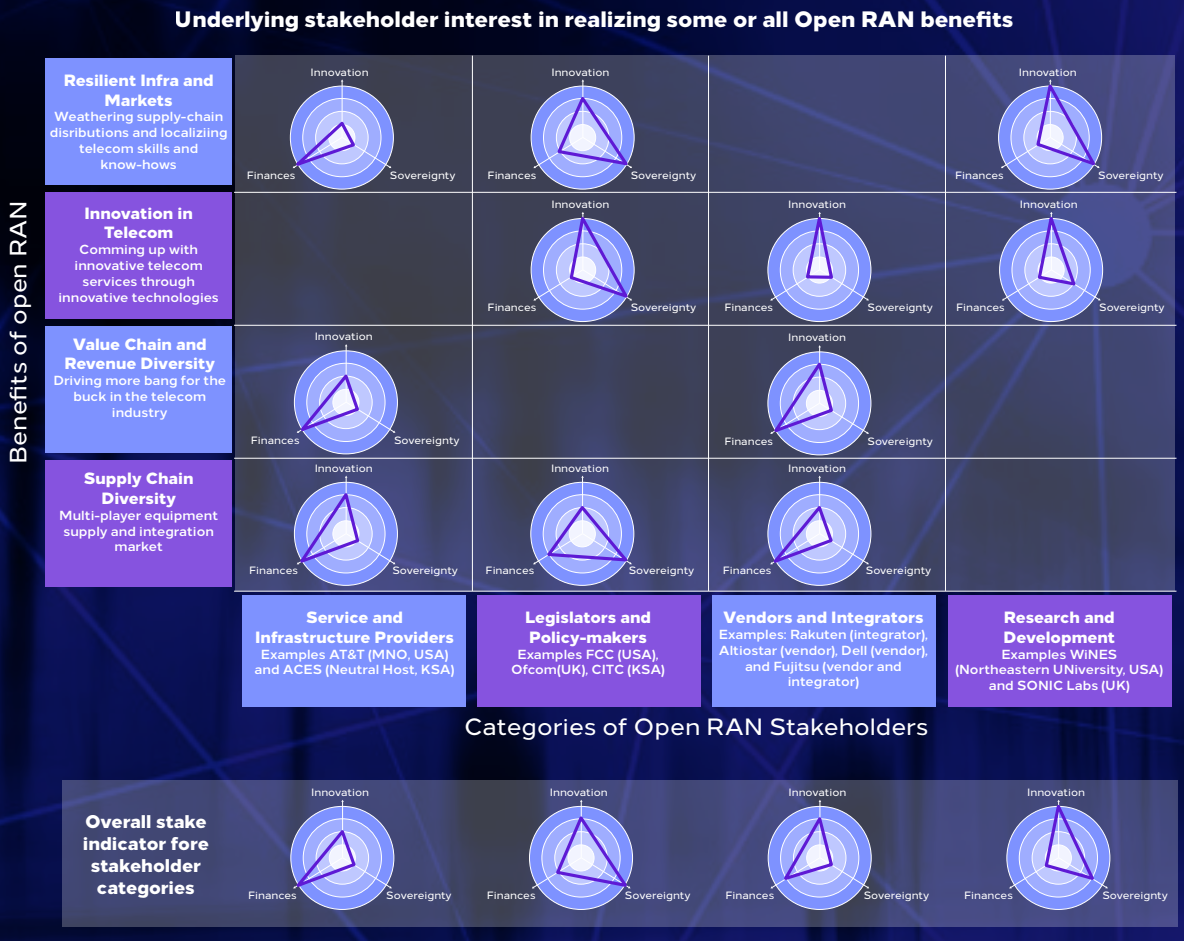


Figure 7: The realization matrix of Open RAN benefits. It cross-references categories of stakeholder with major Open RAN benefits and illustrates the motives for each intersection. At the bottom, the figure depicts the overall stake indicator of a category for reference.

5. Global Momentum and Outlook

Open RAN with its architecture principles has stirred up significant controversy-riddled discussions questioning the status quo of cellular infrastructure as well as the impacts of Open RAN adoption on that infrastructure (benefits of Open RAN in general). This is clear in the amount of white papers, research papers, and notice of inquiries published over the past four years, [2] [5] [27] [28] [18] to name a few examples. This discourse is centered around the three stake dimensions that motivate the adoption of Open RAN—discussed in Section IV—and more specifically on whether Open RAN can deliver on all or some of those dimensions and be able to revolutionize the stagnant infrastructure or not [27] [11]. The discourse has resulted in a global momentum that could be quantified in terms of steps taken by the discourse participants towards either verifying, realizing, or both verifying and realizing the benefits of Open RAN. Those steps are not aligned in a series to form a single path; they form a set of rather diverging paths based on the stake indicator of each participant.

This section will examine the aforementioned momentum. In particular, it will shed light on the most prominent steps taken by some stakeholders and their goals. It will do that through the following two means: (i) paint a picture of the global Open RAN landscape as it stands today, and (ii) preview some of the major efforts and goals of some stakeholders. The landscape picture should illustrate how the interest in Open RAN got sparked, who played central role in getting the idea of developing an open radio access network rolling, and how the community supporting Open RAN looks like today. On the other hand, the second means should provide a brief overview of the prominent steps taken by some stakeholders and what they expect to achieve; more to the point, it will survey the efforts, expectations, and projections of some major stakeholders, with focus on market impact and regulations. Figure 8 graphically summarizes this section in the form of a prominent-event timeline.

A. Landscape Overview

Interest in Open RAN has been mounting up since 2016, but was that the point of origin for the architecture? The answer is surprisingly no, it was not. Open RAN, as a concept, is first proposed by a couple of researchers from CISCO and DoCoMo Communication Lab in an IEEE magazine paper in 2002 [37]. That paper discusses the need for open RAN from a scalability and reliability perspective. It introduces an open RAN architecture that only bares similarity to the modern-day Open RAN architecture from two viewpoints: (i) functional disaggregation and (ii) open interfaces. Despite that, the paper with its open RAN proposal could be considered the actual seed to today's architecture.

Fast-forwarding fourteen years, the extensible RAN (xRAN) forum and Cloud-RAN (C-RAN) alliance joined forces to form the O-RAN alliance in 2018 [38], which is the event that marks the beginning of the modern-day Open RAN concept and architecture.

Both xRAN and C-RAN represented MNO-led efforts to revolutionize the RAN side of the cellular network. By joining efforts, they consolidated their objectives and attracted new endorsements from interested vendors and integrators. The main motivation behind forming the alliance has been reducing expenditure and trying to squeeze more revenue out of the network [2]. However, as more vendors and integrators joined in, the motivation has broadened to incorporate the introduction of innovative features and new value chains, see Sections IV.B and IV.C. Since it was formed, the alliance has a clear target in mind, ramping up and coordinating efforts to put together a set of standards for an Open RAN architecture [6]. These standards are meant to clarify the requirements, specifications, and guidelines to develop and build various RAN components. They also pave the way for the telecommunication industry to transform into a multi-vendor market with diverse supply chains and probably diverse value chains.

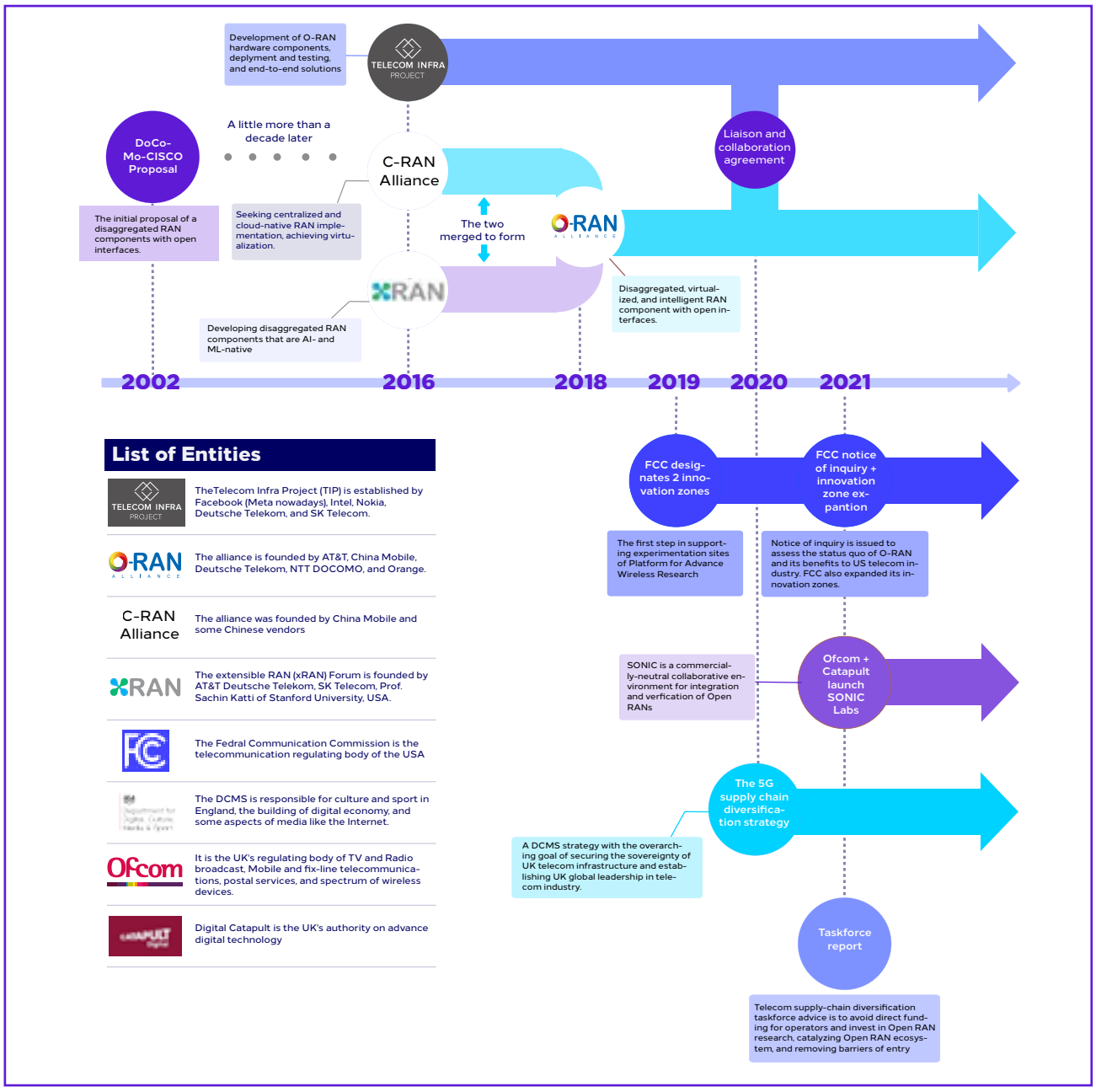


Figure 8: The evolution of the Open RAN landscape summarized in a timeline of some prominent events. It is important to note that the graph is not meant to serve as a comprehensive summary, just a highlight of some important events.

The O-RAN alliance is not sticking out in an Open RAN flatland; other initiatives and teams are also invested in the Open RAN architecture and the concepts it embodies. An almost parallel and complementary effort to that of the O-RAN alliance is the OpenRAN group of the Telcom Infra Project (best known as TIP) [20]. TIP is an initiative that started a little earlier than the O-RAN alliance, in particular in 2016, and it is led by Facebook (Meta nowadays) and a group of operators and vendors, i.e., Intel, Nokia, Deutsche Telekom, and SK Telecom [39]. The initiative has a somewhat broad mission, which is to disrupt the telecommunication industry and its ecosystem in a way that inspires innovation and expands its reach. At its start, the initiative was focused on connecting people in areas that do not have cellular service [40], but with its broad scope, TIP recognizes the disruptive nature of an architecture like Open RAN. Therefore, it has dedicated an operator-led group to contribute to the development, testing, and deployment of Open RANs. More specifically, the OpenRAN group is concerned with the development of Open RAN hardware components, the testing and deployment of end-to-end Open RAN solutions, and the acceleration of Open RAN adoption [20]. Such focus makes the OpenRAN group a complementary effort to that of the O-RAN alliance, which is standardization-oriented.

The landscape is not only dominated by industry-led initiatives, alliances, and work groups; it also encompasses entities with legislative and policy-making power (as discussed in Section IV.A). It is true that the financial motivation behind Open RAN (i.e., the finances dimension) has been playing a strong role in generating the Open RAN momentum, yet it is not operating alone. Legislators and policy-makers have identified Open RAN as a means to foster innovation and bolster infrastructure security and sovereignty [28] [27]. Entities like the UK's Ofcom, the USA's FCC, and Germany's Ministry for Transport and Digital Infrastructure (best known as BMVI), among others, are examples of legislators and policy-makers that are actively contributing to the momentum. They have become prominent landmarks in the Open RAN landscape through funding industry initiatives, sponsoring R&D in academia and industry, and crafting legislations and policies to encourage Open RAN adoption and deployment. All of that accelerates the rate at which Open RAN matures and improves the chance that Open RAN delivers along all its three dimensions, i.e., attaining all three values and their combinations.

Remark on the Position of R&D in the Landscape

Major landmarks in the Open RAN landscapes are defined by entities that belong to the first three categories, i.e., legislators and policy-makers, service and infrastructure providers, and vendors and integrators. Their individual contributions to the Open RAN momentum are substantial, especially in comparison to R&D institutions. This is not surprising considering the stake indicator of R&D institution and the following two observations:

Innovation is a principle dimension for the interest of the R&D institutes. The impact of innovation, however, takes time to materialize as it relies on the maturity of the industry, markets, and regulations surrounding Open RAN. For instance, a disrupting technology that is developed for the Open RAN architecture might not be adopted as soon as it emerges, for the Open RAN architecture itself is still in its formative stages and is not prevalent yet.

Infrastructure sovereignty is another principle dimension for this category. The stakeholders contribute along that dimension by fostering individuals' skillset and cultivating know-how. Such process is contingent on the maturity and prevalence of the Open RAN architecture. Hence, its impacts need time to make a mark on the Open RAN landscape.

This is why, moving forward, the discussion will be inclined to focus on steps, goals, and expectations of first three categories.

B. Legislative and Policy-making Efforts

Legislators and policy-makers are heavily invested in verifying and realizing the expected impacts of Open RAN along the dimensions of infrastructure sovereignty and inspiring innovation. They view the supply-chain diversity, which is an intrinsic benefit of the Open RAN architecture, as a means to achieve three important goals [24] [5] [11]: (i) guarantee vibrant telecommunication industry with multiple local vendors, (ii) ensure resilient telecommunication infrastructure and markets, and (iii) dial up the local competition in the telecommunication industry to a creative level. All that is clear in prominent steps taken by many government institutions, especially in Europe and North America. Their efforts, in general, manifest in the form of direct and indirect incentives to ramp up Open RAN development, testing, and deployment, which are collectively termed the incentivize-to-realize approach. An overview of some of those efforts is presented below and graphically summarized in Figure 8.

The USA's Federal Communication Commission (FCC)

FCC has adopted an indirect approach to incentivize the telecommunication community (including operators, vendors, academia… etc.) to work on Open RAN and help achieve the three goals above. In March 2021, it issued a notice of inquiry in which it was seeking feedback from the different constituents of the US telecommunication industry (e.g., network operators, equipment vendors, government organization, research centers… etc.). The inquiry focuses on the following questions: at which stage is the architecture development? and what are the steps required to deploy Open RAN at scale [27]?.The response to that inquiry have covered a wide spectrum of opinions; it extends from fully supporting and commending the commission's interest in the architecture all the way to advising caution and impartial involvement in the course of Open RAN development and deployment, see for instance [32] [41] [7].

Following its notice of inquiry, FCC has established two additional innovation zones that promote testing platforms for the integration of Open RAN [10]. The announcement was made on August 2021, and it awarded innovation zone status to two test sites that belong to the Platforms for Advanced Wireless Research (PAWR). Those sites are in Raleigh, NC and Boston, MA. The new zones are added to another two zones that were established earlier in New York City, NY and Salt Lake City, UT. The innovation zone status provides experimental licenses within certain geographical locations to qualified research groups. This allows researchers access to a wide range of frequencies with flexible sharing and utilization regulations [10] [42]. The four innovation zones are managed by PAWR, which is backed by a USD 100 million funding from the US National Science Foundation (NSF) and a consortium of 30 telecommunication companies and associations [43].

The description of the innovation zone and their experimental licenses outright state the objective for establishing them; they promote innovation through research in advance wireless communication technologies and its related fields, Internet of Thing (IoT) and Unmanned Aerial Vehicles (UAV), among others. This makes them general incubators of innovation in telecommunications and not biased to a certain technology or architecture. Open RAN research falls within their scope but does not restrict it. Hence, they are indirect means of supporting Open RAN development, testing, and

deployment, as well as being indirect means of verifying and realizing the benefits of Open RAN.

The UK's Office of Communications (Ofcom)

Different than its North American counterpart, Ofcom has adopted a hands-on incentivize-to-realize approach to promote the development, testing, and deployment of Open RAN. The regulator along with its government-backed partner Digital Catapult has launched the SmartRAN Open Network Interoperability Center (SONIC) labs [9]. The labs are meant as a commercially-neutral and collaborative environments for developing disaggregated Open RAN components and testing the integration and interoperability of Open RAN and network solutions. Those labs represent a neutral innovation-oriented zones for telecommunication and, more specifically, testing and verification of new solutions. They encourage telecommunication entrants (e.g., start-ups and small and medium enterprises) to develop Open RAN components and software. The labs also serve as a means to lower the entry barrier for start-ups, new services, and new products.

SOINC labs as well as the efforts of Ofcom and Digital Catapult fall under a big strategic umbrella the government of the UK has set up. They are parts of a national overarching 5G supply chain diversification strategy that the UK government defined in late 2020 and backed up with GBP 250 million [25]. The strategy has three major targets: (i) supporting incumbent suppliers to ensure their resilience and ability to supply the market in the near future, (ii) attract new suppliers into the UK market to build resilience and competition, and finally (iii) accelerating open-interface solutions and deployment to avoid single vendor lock-ins. A monumental element in the strategy is the forming of the 2021 "telecom diversification taskforce." The taskforce scope is to deliver suggestions on candidate courses of action for the strategy with focus on Open RAN and its potential [28]. One of its most important findings advises the UK government to avoid direct funding to MNOs for the sake of accelerating the adoption and deployment of a certain technology or architecture. Rather, it identifies the following points as best course of action to derive value for the government's money: (i) appropriating funds to support research and development in Open RAN, and (ii) catalyzing the UK ecosystem and removing barriers to entry. Both points manifest in the launch of the SONIC labs.

C. The Open RAN Market

The market impact of the architecture is amongst the most heated discussions surrounding the Open RAN movement. This stems from the fact that Open RAN is an operator-led movement with business-oriented objectives as well as participants from various corners of the telecommunication industry. As mentioned earlier in Sections IV and V.A, MNOs are major constituents of the second category of Open RAN stakeholders. They have huge expectations for Open RAN as a means to improve finances—this is the first dimension of motivation behind their interest in Open RAN—and more specifically reduce infrastructure expenditure and generate new streams of revenue [2] [17] [4] [12]. Their vendors and integrators fellows (i.e., constituents of third category) have similar financial interests, but they are focused on new revenue streams and claiming larger share of the equipment supply business than they hold now [5]19] [7]]. As a result, a lot

of effort has gone into analyzing the dynamics of global telecommunication markets, the position of Open RAN in those markets, and the financial benefits Open RAN could bring about, the ABI Research and ACG Research studies [11, 3] to name two examples.

This section is a zoom in on the business side of the Open RAN landscape discussed in Section V.A. In particular, it explores the efforts of stakeholders in the second and third categories, namely service and infrastructure providers and vendors and integrators, through the lenses of: (i) projected financial impact, (ii) current composition of Open RAN ecosystem and real-world deployments, and (iii) open questions and challenges. The first point highlights the expected financial benefits of Open RAN which are the main, yet not the only, driver of interest for the stakeholders in both categories. The second point is an attempt to shed light on the position of Open RAN in the telecommunication industry and its maturity level. Both points look at the bright side of Open RAN. Hence, a reality check is needed to balance the discussion. This is exactly what the last point aims to do, for it explores challenges, concerns, and still-unanswered questions about Open RAN.

Projected Revenue and Market Share

Traditional RANs dominate the telecommunication scene today with some noticeable competition from Open RAN [11]. Thus, it is still not clear whether Open RAN can deliver on its promise to improve the finances of MNOs, vendors, and integrators (the first dimension of motivation, see Section IV). ABI Research, Analysys Mason, and ACG Research have all investigated, modeled, and projected the financial benefits of Open RAN over the next three to six years [12, 3, 11]. They have used different deployment scenarios and modeling tools, yet they have arrived at similar findings; Open RAN is, to some extent, lucrative.

Part of the study from ABI Research focuses on the market share for Open RAN compared to that of traditional RAN. It attempts to identify whether, and if so, when, the Open RAN will overtake the traditional RAN architecture. It projects the revenues coming from deploying Open RAN and traditional RAN over the period from 2021 and 2030, see Figure 9. The projection indicates that the RAN market as a whole is expected to grow with a Cumulated Annual Growth Rate (CAGR) of 5%. This may seem like a slow growth, but a closer look at the figure shows that it is due to the shift from the traditional RAN deployment to Open RAN deployment. The projections indicates that Open RAN will exponentially grow in revenue over the period between 2021 and 2030. By the year 2028, Open RAN is expected to overtake its traditional rival; it will become the mainstream deployment architecture, and it will secure a CAGR of roughly 30% by the year 2030.

The growing trend forecasted in the study of ABI Research is not quite off-base, for Analysys Mason [12] and ACG Research [3], both, back it up with their findings. They do not project revenues over ten years per se. Rather they estimate saving percentages achieved with Open RAN in comparison to traditional RAN deployment, specifically savings in terms of Total Cost of Ownership (TCO), CAPEX, and OPEX. Approximately 30% TCO savings in comparison to traditional RAN is reported by Analysys Mason [12] using their own TCO model. This estimate is for brownfield deployment case and is over the span of three years. Greenfield deployments are reported in the ACG Research

study [3]. Using a proprietary TCO model, the report finds that Open RAN could provide between 28% to 35% TCO savings compared to traditional RAN, depending on the deployment scenario chosen. All those two findings support the projections of ABI Research; they all suggest that Open RAN has a competitive edge over its traditional counterpart, and, subsequently, it is more desirable for new deployments and network expansions than a traditional RAN.

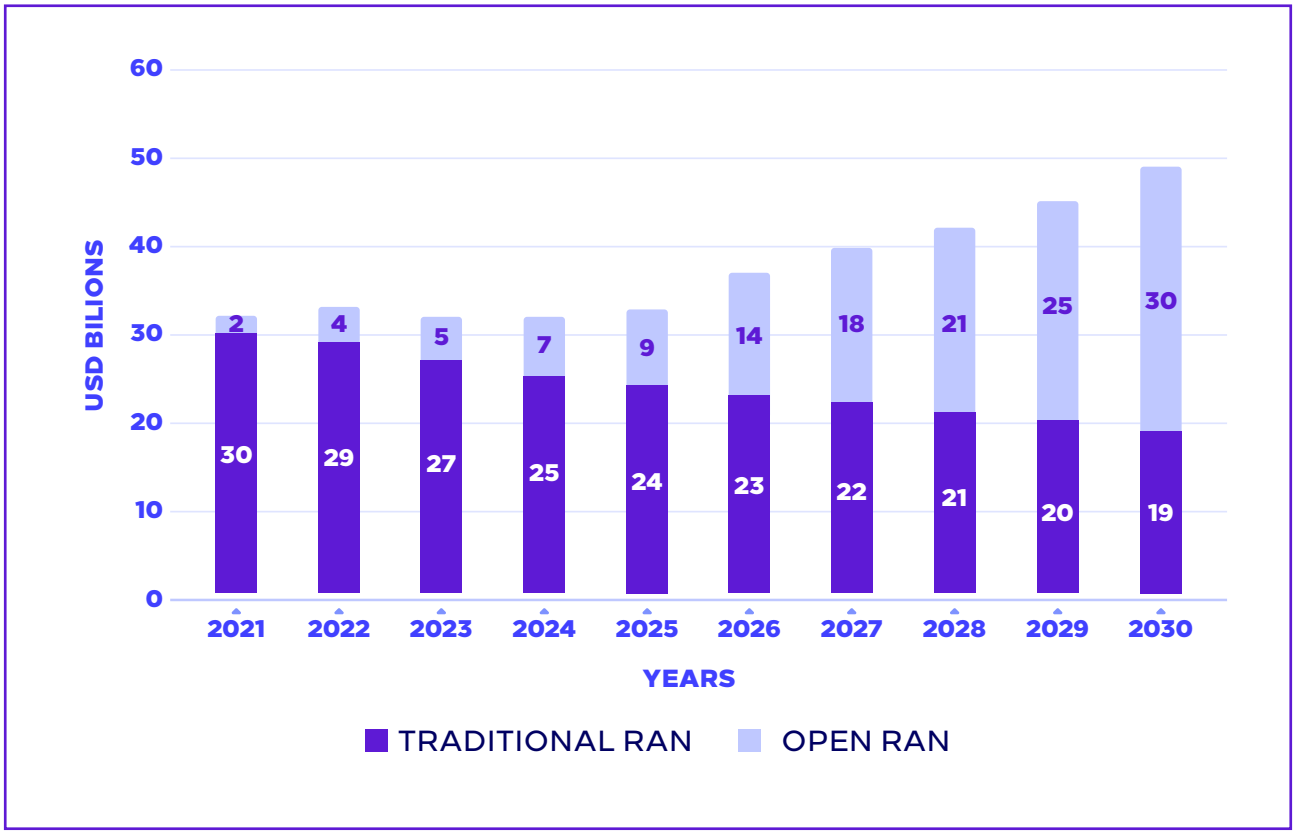


Figure 9: Projection of Open RAN and RAN revenue over a decade (brownfield and greenfield). It is based on 2020 data, and it shows an inflection in 2028 when Open RAN takes over and becomes dominant (source: ABI Research [11]).

Ecosystem and Real-World Deployments

Open RAN is no longer a dreamy idea locked up in a research and development laboratory somewhere. It is rather a reality with multiple deployment cases and ecosystem of component suppliers and network operators [17] [8]. As of 2021, iGR reports that approximately 22 MNOs around the world have started commercial deployment of Open RANs. The surveyed MNOs span developed and developing countries alike with rural and urban deployments [17]. Figure 10 illustrates the geographical extent of global Open RAN deployments as well as trials. The experience of some MNOs with Open RAN is briefly presented below in a way that reflects the experience maturity:

Rakuten	**A Japanese MNO** A Japanese MNO with the world's largest cloud-native Open RAN network [17].	**4000 cell sites** They have deployed over 4000 cell sites [17]	**40% CAPEX** They are claiming 40% CAPEX reductions compared to traditional RAN [8]	**Multiple vendors** It contracted multiple vendors for RAN components including but, not limited to, Altiostar, Airspan, and Nokia [8]
dish	**A US MNO** A US MNO with an Open RAN cellular network.	**20% coverage** The operator has covered almost 20% of the US with 5G broadband, and it targets a 70% coverage by 2023 [51].	**Several vendor** It has several vendors for its Open RAN network, including Mavenir, Altiostar, MTI, Qualcomm, Intel, and Fujitsu [8]	**USD 20 billion** The company has invested USD 20 billion so far in spectrum acquisition [8]
vodafone	**A European MNO** UK, Ireland, and Turkey deployments of Open RAN cell sites within their networks that are dominated by traditional-RAN deployment [17].	**+2500 sites** It has pledged +2500 sites within the UK for Open RAN deployment in 2021 [34].	**Vendor selection** Vendor selection includes Samsung, Dell, NEC, Wind River, Capgemini Engineering and Keysight Technologies [34]	
AT&T	**The US MNO** The US MNO giant has been committed to deploying Open RAN sites since 2021 [52].	**Deployment** In 2022, they are targeting Open RAN deployments in buildings [52]	**Standardization bodies** AT&T is actively contributing to multiple standardization bodies invested in the Open RAN architecture and its development, e.g., O-RAN alliance, TIP... etc.	

The accelerating adoption of Open RAN is supported by a growing telecommunication ecosystem of key-players. It encompasses the usual players like MNOs, incumbent equipment vendors, customers, and value-added partners, and it is expanding to accommodate new ones, like virtualization and containerization software developers and server and computing equipment suppliers. The advent of Open RAN is even enticing some of the legacy players to assume new additional roles, like Samsung developing RAN virtualization software when it is widely recognized in the telecommunication industry as an original equipment manufacturer (OEM) and legacy RAN vendor [34]. Within the complex telecommunication ecosystem, Open RAN has started forming its own ecosystem. It encompasses incumbent and emerging vendors

and integrators. Roughly the players of the Open RAN ecosystem could be grouped into five major categories [11]: (i) Radio Unit (RU) hardware and software suppliers, (ii) Distributed Unit (DU) and Central Unit (CU) hardware suppliers, (iii) RAN virtualization and software suppliers, (iv) chipset suppliers, and (v) system integrators. The five groups and their roles are illustrated in Figure 11 with some example players.

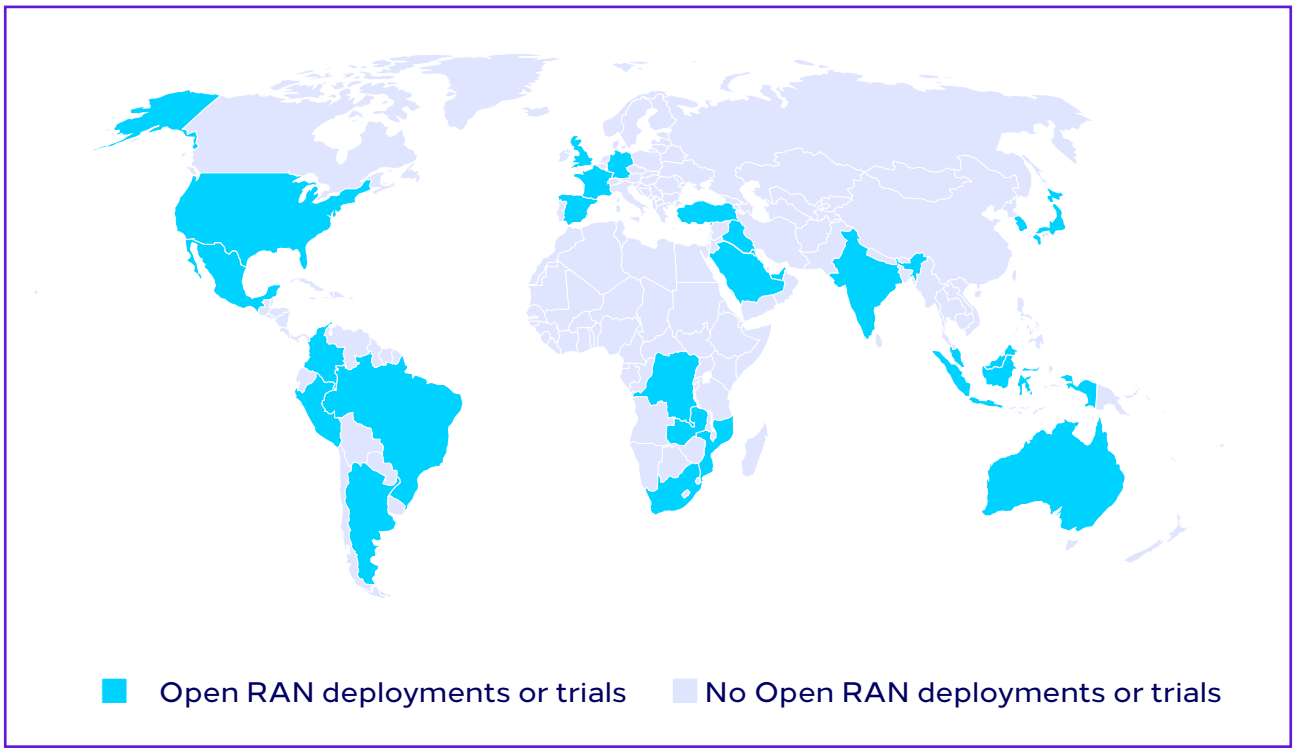


Figure 10: Global Open RAN deployments and trials as of 2021 [8] [17].

Challenges and Questions

"Open RAN is still in its formative stages" is a statement emphasized by serval stakeholders (e.g., FCC [27]), one that is especially true from a market perspective. Some stakeholders in the second and third categories are still skeptic about the need or importance of Open RAN in spite of all the promise discussed in the previous two subsections [44, 8, 33]. Three of their most popular concerns are discussed below

Greenfield deployments only: Some stakeholders believe Open RAN represents a radical shift in cellular network construction and architecture, and, hence, it is only suitable for greenfield deployments [8] [11]. The argument here is that new locations can deliver the CAPEX savings Open RAN boasts, for there is no prior system in place. Yet, ripping and replacing existing traditional equipment has higher CAPEX costs compared to upgrading them. This concern implies that Open RAN needs a lot more time than what its fans has estimated to mature and become mainstream.

What about OPEX costs? This is an interesting question that is drawing some attention within the telecommunication industry [12]. Diversifying the RAN supply chain through disaggregation and virtualization may lead to less CAPEX than traditional RAN, yet it means a more complex system which needs costly integration.

As different vendors may provide components with varying performance and manufacturing quality, system integrators will need to put in more effort to integrate the hardware components, harmonize the software components, and insure full interoperability. All that translate into inflating OPEX costs, which may offset the CAPEX savings.

Disaggregation threatens infrastructure sovereignty and security: Although it is not a main objective of the stakeholders in the second and third categories, some concerns have surfaced on the actual value Open RAN offers for infrastructure sovereignty [8] [44]. The basis of that concern is rooted in disaggregation and open interfaces. The former implies the need to contract multiple vendors to procure components, which increases the risk of installing untrusted equipment and running into a security-compromising situation. The latter, on the other hand, suggests the existence of week points in the system; the exchange of data (whether control or user data) could, thus, be jeopardized.

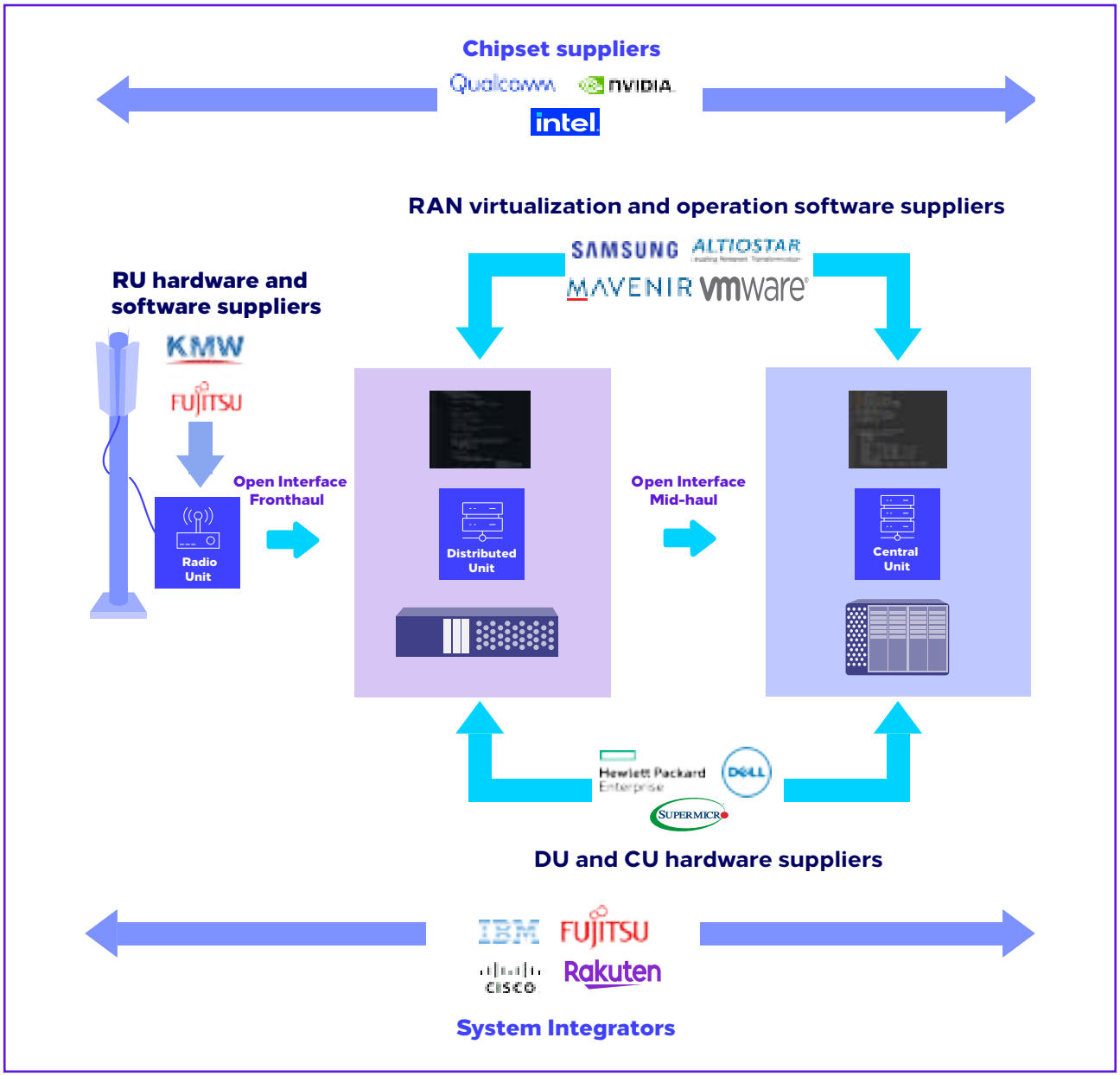


Figure 11: The ecosystem categories for the Open RAN architecture with some example vendors and manufacturers.

6. The Shaping Saudi Landscape

The Kingdom of Saudi Arabia (KSA) is undergoing a huge socio-economic transformation defined by its master plan Vision 2030 [45]. Its transformation stands on three pillars: (i) A vibrant society, (ii) a thriving economy, and (iii) An ambitious nation. All of those are impacted by the Information and Communications Technology (ICT) sector of the Kingdom, in which the telecommunication industry represents a major, if not the largest, segment. A scalable and innovation-hospitable telecommunication infrastructure has the potential to connect more people (impacting the first pillar), improve the finances of the telecommunication industry (impacting the second pilar), and encourage and promote innovation across the country (impacting the third pillar). The Open RAN architecture as it stands today is an enabler to that scalable and hospitable infrastructure, and, hence, it is of interest to both the government of KSA and its telecommunication industry. Below is a brief overview of that interest.

A. Interest and Efforts

Interest in Open RAN has been building up for a while in Saudi Arabia as evident in STC's membership in the O-RAN alliance [15], the Memorandum of Understanding (MoU) among several leading MNOs in the Gulf Corporation Council (GCC) region [46], and the Memorandum of Corporation (MoC) between the governments of Saudi Arabia and the United States [16]. That interest is spread across all segments of the telecommunication industry, i.e., MNOs, neutral hosts, vendors, legislators, and policy-makers, which form the set of local Open RAN stakeholders. Similar to their global counterparts, the motivates underlying the interest of those stakeholders in Open RAN is contained within the stake space defined by the three values: improved finances, inspiring innovation, and bolstered infrastructure sovereignty. The interest has resulted in a few milestones so far, which are summarized in the following three points:

Efforts of STC: STC is an operator member of the O-RAN alliance, which reflects clear interest in the architecture. In its efforts to realize the Open RAN benefits, the company has partnered with several notable vendors and operators to trial Open RAN stacks for brownfield deployments [13]. It has an MoU with Rakuten Mobile Inc. to explore ways of deploying Open RAN sites, both brownfield and greenfield deployments. In collaboration with Mavenir, STC has recently announced the successful deployment and testing of a 4G and non-standalone (NSA) 5G site operating with Open RAN architecture [47]. The company has stated in a recent white paper that the results of its Open RAN trials are "optimistic" and indicate the need for further hardware and software developments before large-scale brownfield deployments are attempted [13].

The GCC Open RAN Consortium: The major Saudi MNOs, namely STC, Zain, and Mobily, have joined forced with other MNOs in the GCC region to push forward the

adoption of the Open RAN architecture. The three MNOs have signed a MoU with e&, du, OmanTel, and Bateco forming a regional consortium. They will share industry knowledge and experience to advance brownfield deployments of Open RAN sites. The consortium has recently collaborated with TIP and Intel to launch a community Open RAN lab in the GCC region [14].

Saudi-USA MoC: Parallel to the industry efforts, summarized above, the government of Saudi Arabia has signed an MoC with its United States of America counterpart in the fields of 5G and 6G technologies, with focus on Open RAN. It targets accelerating the growth of the Kingdom's digital economy and R&D [16]. The MoC is signed by the Ministry of Communications and Information Technology (MCIT) in Saudi Arabia and the National Telecommunication and Information Administration (NTIA) in the USA [48]. It serves as a catalyst for research, development, and innovation in various advanced telecommunication directions in the Kingdom, which includes Open RAN.

B. Potential and Outlook

The potential Open RAN holds for the global telecommunication industry could be directly projected onto the Kingdom's industry. All major benefits discussed in Section III.B could be of interest to the local stakeholders. However, with a growing digital economy like the Kingdom's and with a national transformative plan like Vision 2030, it is worthy to revisit the benefits of Open RAN and contemplate their expected local impact.

Leveling the playing field and encouraging the emergence of local vendors: Open RAN creates supply-chain diversity, which is enabled by three Open RAN principles, namely disaggregation, virtualization, and open interfaces. The three, collectively, help lower the entry barrier to the telecommunication equipment market, which is an implication worthy of pondering for the Saudi Arabian telecommunication industry. As an ambitious nation with a growing economy, the Kingdom could leverage Open RAN to catalyze a new local industry, one that is centered around the RAN infrastructure. Startups and enterprises could engage in the development and integration of RAN software or/and hardware components. This leads to growth in the local telecommunication industry, and it paves the way for the Kingdom to become a global key player in the telecommunication equipment industry (i.e., gaining further influence in the development of next generation cellular and emerging technologies).

Cultivating local know-how and skillsets: Open RAN transforms the telecommunication infrastructure towards becoming elastic and interoperable. These two characteristics are essential for value-chain diversity and telecommunication innovation—two major benefits of Open RAN. They could also be of special importance to the Kingdom, for they imply a more hospitable telecommunication environment for research, development, and innovation. An environment like that could help get more individuals engaged in research and development activities and stimulate creative and entrepreneurial minds to try on novel ideas and roll out new products. All that leads to the fostering of experience and talent, which are essential ingredients to the MCIT's ICT strategy 2019-2023 [49] as well as Vision 2030 [45].

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