Open Radio Access Network (RAN)

How Fast Can We Get There?

A Technical Paper prepared for SCTE by

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1. Introduction

As mobile operators transition from 4G to 5G, one of the biggest parts of the mobile network experiencing transformation is the Radio Access Network (RAN). This transformation includes virtualization, disaggregation, open interface, intelligence, and cloudification, which are foundational components to an Open RAN architecture and complements the service-based architecture envisioned for 5G.

Today, mobile networks typically consist of proprietary software integrated onto customized hardware designed by a single mobile network supplier. Network upgrades or fixes require systematic deployment and validation to each of the network subsystem functions and, in some cases, lead to an entire network overhaul. Mobile operators are locked into the development, release pace, and schedule of the network supplier, which can significantly impact network operation, offered services, and deployment plans. This industry dynamic increases costs, slows innovation, and reduces competition.

The industry is attempting to change this single vendor paradigm ('vendor lock') by developing industry standards to disaggregate proprietary software from the hardware and open proprietary interfaces between network subsystems and functions to allow for network supplier interoperability.

With a recent increase in mobile network operators (MNOs) trials, industry Plugfests, and standards development, the industry has quickened the pace towards achieving Open RAN, which has the vision of RAN components as a virtual software application capable of working on any bare metal hardware operated with orchestration and automation. The mobile industry is at a tipping point where non-traditional network suppliers are gaining momentum in developing Open RAN solutions that are maturing and becoming commercially viable, reliable, and scalable to the operator community.

MNOs are assessing many factors and dependencies that are key to the transition of mobile networks to Open RAN, including the commercial and economic viability of Open RAN. As part of the considerations, MNOs must leverage current infrastructure investments to expand networks while developing a road map for future growth and purchase cycles.

For several years, CableLabs evaluated the progress of Open RAN architecture and conducted several lab investigations in collaboration with Telecom Infra Project (TIP), O-RAN Alliance, and the National Telecommunications and Information Administration (NTIA). To assist in this assessment, CableLabs undertook an investigation of Open RAN transition approaches and key indicators for assessment with learnings from lab activities of industry generated and representative common operator deployment scenarios. As a result, this paper will address the following topics[1]:

- Analyze the current state of the Open RAN ecosystem.
- Discuss learnings of external and internal CableLabs Open RAN test activities.
- Develop an Open RAN transition approach with assessment criteria.

2. Background

The evolution of wireless communication networks has led to the introduction of fifth generation (5G) technology, which promises to deliver unprecedented speeds (enhanced Mobile Broadband (eMBB)), ultra-low latency (ultra-reliable Low Latency Communications (URLLC)), and massive connectivity (massive Machine Type Communication (mMTC)). To support the use cases promised by 5G networks,

[1] Note that Open RAN economics are out of scope of this paper and have been addressed in detail in previous CableLabs Technical Briefs

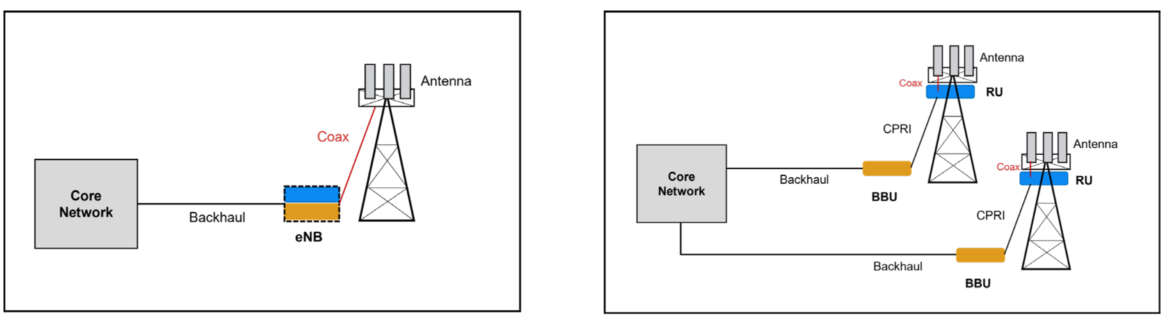
the RAN plays a crucial role. Traditionally, the RAN has been dominated by proprietary and vertically integrated solutions offered by a handful of established vendors. However, with the emergence of Open RAN, the landscape is undergoing a significant transformation by reducing the barriers to entry and broadening the vendor ecosystem.

To better understand the emergence of Open RAN, an overview of the transitional changes to the RAN architecture in 4G and 5G is described below, which introduces foundational elements of centralization, disaggregation, and virtualization into the RAN architecture.

2.1. Distributed and Centralized RAN (D-RAN and C-RAN)

During the rollout of 4G networks, the RAN transitioned from a ‘monolithic’ integrated eNB (i.e. LTE base station), where radio elements are integrated and housed in a single enclosure with coax to the antenna, to a Distributed RAN (D-RAN) architecture where the radio elements of the RAN is split into the Radio Unit (RU) and Base Band Unit (BBU), as shown in Figure 1. The RU consists of the lower physical layer of the radio protocol stack, converts RF signal into data signal and vice versa, and includes components such as RF filters and high-power amplifiers connected to the antenna.

The BBU manages the entire base station, including signal processing, operation, and maintenance, and consists of all the radio protocol stack layers except the lower physical layer. Each cell site with its radio functions is distributed and connected with a single backhaul connection to the core network. The BBU-RU interface replaced the traditional coax cable with optical fiber managed by the Common Public Radio Interface (CPRI) protocol. The BBU and RU can be housed in the same enclosure or separated by a short distance for instance, residing on a tower close to the antenna.



Integrated eNB | Distributed RAN

Figure 1. Integrated eNB vs Distributed RAN

The D-RAN later evolved to a Centralized RAN (C-RAN), where a ‘pool’ of BBUs is centralized at a local hub or data center close to the cell site, as shown in Figure 2. This enables the Radio Units (RUs) to be up to several miles away from the BBUs. The RUs became Remote Radio Units (RRUs) since they can be separated by a relatively long distance from the BBUs. This allows for the cell site to only include the RRU and the antenna. This also results in a new interface between the RRU and BBU pool called the ‘fronthaul’.

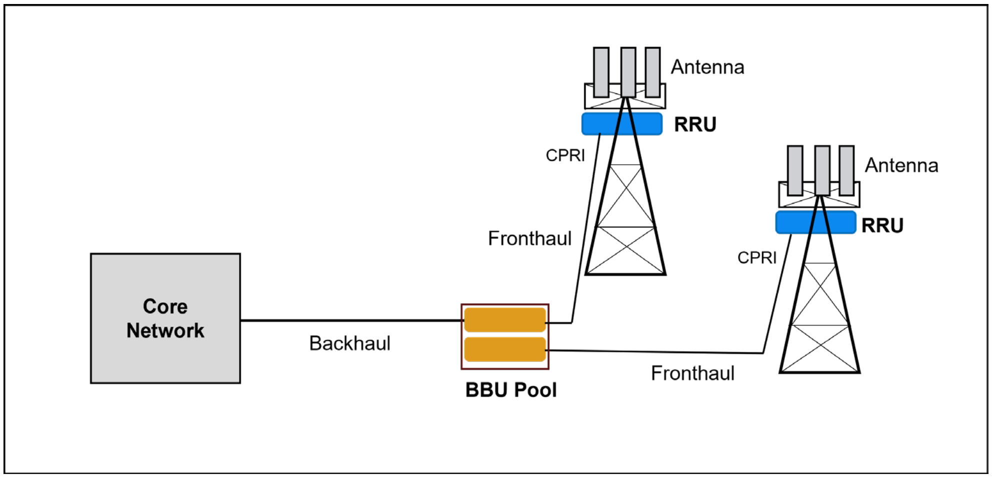


Figure 2. Centralized RAN

The C-RAN architecture can pool multiple RRUs to a single BBU pool and extend beyond a 1:1 mapping to a 1:N mapping of BBU to RRU. This provides capital and operational expenditure (CAPEX and OPEX) benefits of reduction in deployment and maintenance cost by requiring fewer routers, reduced electricity usage, and reduced real estate needs. The end-to-end latency can be further reduced with edge computing where an application server can be placed in or close to a hub or data center. Advanced features such as Coordinated Multi-Point (CoMP) can be supported due to low latency communications made feasible by the proximity of the BBUs in a data center. In addition, it improves spectral efficiency and reduces inter-channel interference since centralized BBUs can share resources dynamically with multiple RRUs using joint scheduling and processing. The 5G RAN (i.e., gNB) also utilizes the integrated RAN, D-RAN, and C-RAN architectures similar to 4G LTE.

2.2 5G RAN Split Architecture

Disaggregation

The 3rd Generation Partnership Project (3GPP) 5G Release 15 specifications laid the initial foundation for the 5G RAN which includes further disaggregation of the RAN into multiple components, as shown in Figure 3.

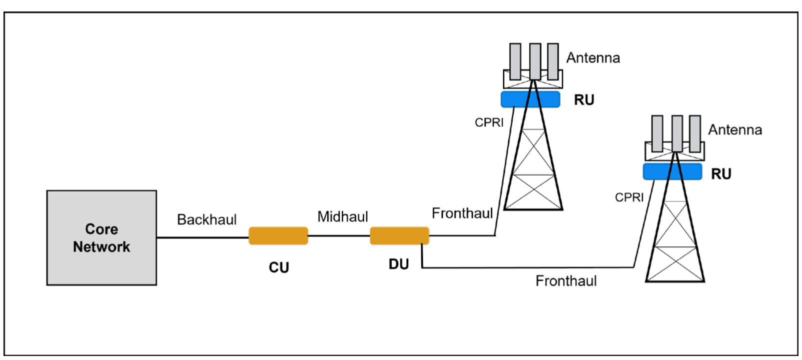


Figure 3. Disaggregated RAN

The 3GPP architecture divides the gNB into two logical components, the gNB-Central Unit (gNB-CU) and the gNB-Distributed Unit (gNB-DU). The gNB-CU implements the upper layers of the radio protocol stack for the Control Plane and User Plane and includes the Radio Resource Control (RRC), Service Data Adaptation Protocol (SDAP), and Packet Data Convergence Protocol (PDCP) layers. The gNB-DU implements the lower layers of the radio protocol stack for the Control Plane (CP) and User Plane (UP) and includes the Radio Link Control (RLC), Media Access Control (MAC), and Physical (PHY) Layer. A new interface is introduced called the 'Midhaul' that connects the CU to the DU. From the 3GPP perspective, the gNB-DU includes the entire PHY layer, however, this can be further divided into Upper PHY and Lower PHY based on implementation-specific requirements. The Upper PHY manages baseband processing (previously in the BBU) and the Lower PHY manages RF processing. The gNB-CU can interface directly with the core network or with other gNB-CUs and gNB-DUs. In addition, the gNB-DU can directly interface with multiple RUs and other gNB-DUs and gNB-CUs.

From a 3GPP perspective, the gNB-CU and gNB-DU utilize an F1 interface between them and further separates the CP and the UP. The CP protocol uses F1 Application Protocol (F1AP) and the UP protocol uses General Packet Radio Service (GPRS) Tunneling Protocol. Thus, this decomposition goes into a gNB-CU-UP and gNB-CU-CP interfaces on the F1 with an E1 interface between them that is managed by the E1 Application Protocol (E1AP).

The benefits of disaggregation of the gNB include increased flexibility, scalability, and interoperability to realize 5G use cases and enable the RAN to support multiple logical paths over the same physical path that allows for innovative service delivery to multiple user types over the same network. 3GPP Release 16/17/18 will include a fully featured 5G network using Service Based Architecture (SBA) that will include virtualization and cloudification of the network that lays the foundation for the core to be extended into the RAN.

Functional Splits

With the advent of 5G, the industry realized the need for further standardization of the radio protocol stack layers within the disaggregated RAN and created functional splits. 3GPP TR 38.801 provides definitions of these multiple 'split' variants to the 5G RAN architecture shown in Figure 4. The functional RAN split options provide a standardized arrangement of radio stack layers within the disaggregated RAN to allow for flexibility in design and deployment of the 5G RAN to meet capacity, coverage, and latency requirements.

The architecture of a 5G RAN depends on the architectural split selected by the MNO. The 3GPP standard provides multiple options or 'splits' of functionality based on building blocks shown in Figure 4. The various functions can then be performed by the CU, DU, or RU depending on the option chosen. As shown in the lower portion of Figure 4, common splits include: (1) 5G high layer split (F1) (option 2) with a CU and DU/RU; (2) 5G low layer split (Fx) (option 7) with a CU/DU and RU; and (3) 5G cascaded split (option 2 and option 7) with a standalone CU, DU, and RU. The higher layer splits are well suited for low bandwidth requirements and are latency tolerant - ideal for low latency, edge computing, and non-mobile use cases such as Fixed Wireless Access (FWA). While the lower layer splits are well suited for high bandwidth requirements and are latency constrained – ideal for mobile use cases such as Coordinated Multipoint Access (CoMP).

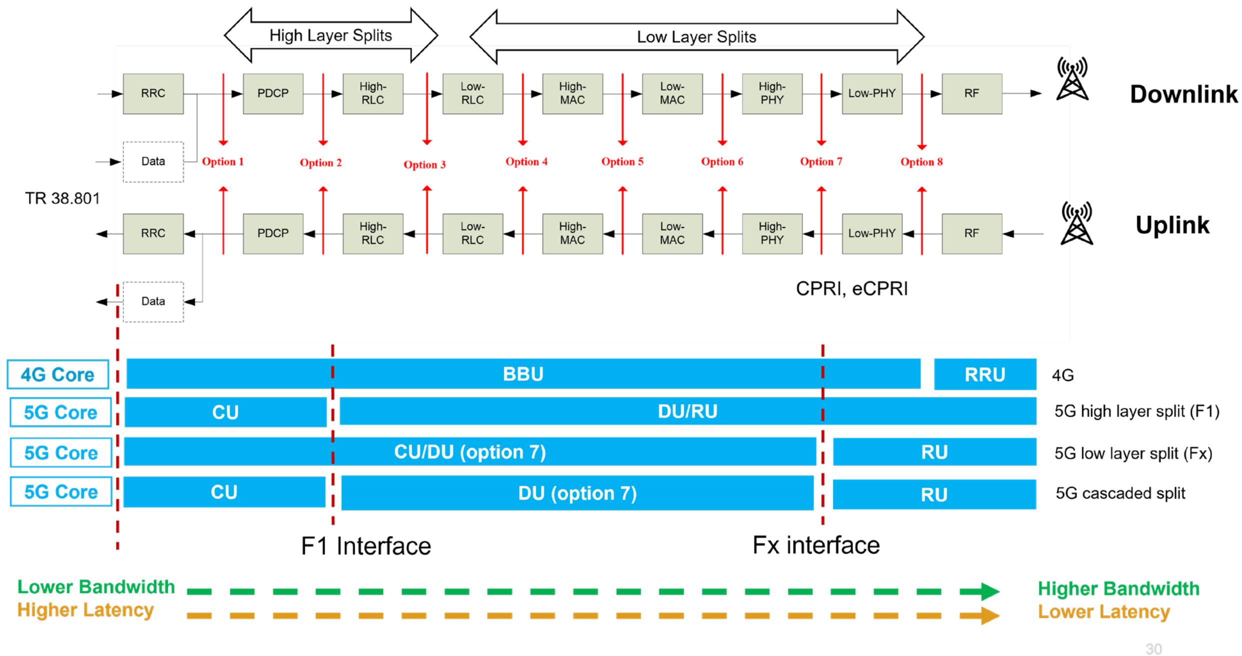


Figure 4. 3GPP 5G RAN functional split options

Various configurations and usages of 5G RAN functional splits are compared with the traditional monolithic 4G BBU-RU architecture in Figure 5. The choice of which option to use depends on several factors including deployment scenarios, network constraints, and intended supported services.

- Support for specific Quality of Service (QoS) per offered services (e.g., low latency, high throughput)
- Support for specific user density and load per geographical area (RAN level coordination need)
- Transport network availability – ideal to non-ideal
- Application type – Real-time or Non- Real Time Radio Access
- Network feature requirement – such as Carrier Aggregation, Coordinated Multipoint Access (CoMP), Enhanced Inter-Cell Interference Coordination (eICIC)

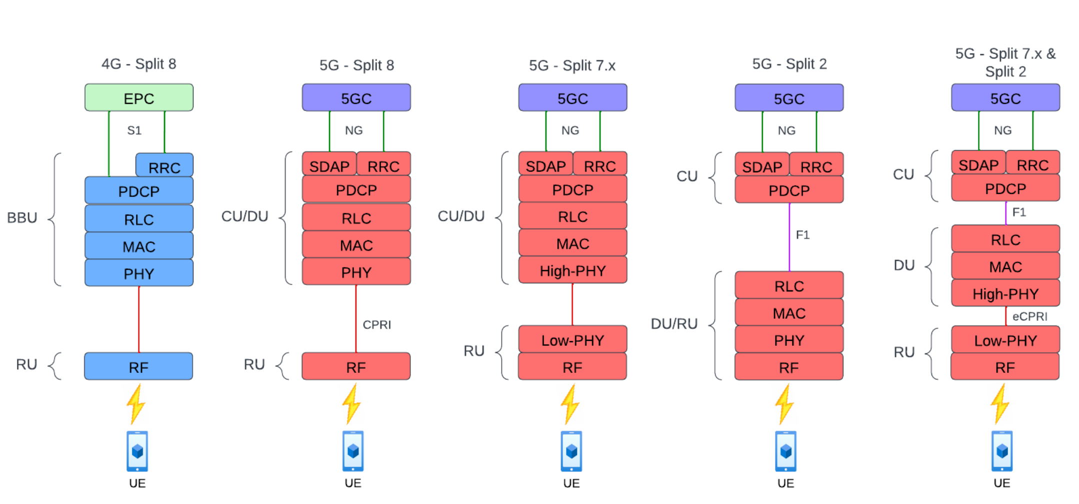


Figure 5. Deployment configurations of 5G RAN functional split options

3GPP only supports split option 2, which is commonly used by many operators today with an integrated DU and RU and standalone CU to support high bandwidth, low latency deployment scenarios such as densification of small cells. As previously mentioned, the 3GPP also supports gNB-CU-UP and gNB-CU-CP on the F1 interface as further decomposition of the CP and UP to the option 2 split as shown in Figure 6.

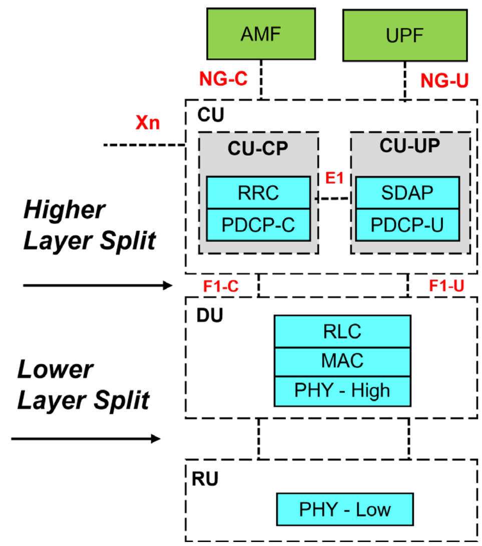


Figure 6. Lower and higher layer splits with separate user and control plane in the CU

Furthermore, as part of this transition, the CPRI specification was improved to enhanced CPRI (eCPRI), a new protocol to connect the DU and RU that uses ethernet as its physical layer and runs over fiber. eCPRI provides a faster link rated at 10-25 Gbps and a more efficient use of fronthaul bandwidth (point to multipoint from point to point). 3GPP does not address the fronthaul interface.

2.3 Virtualized RAN (vRAN)

Another transformation of the RAN is the virtualization of the RAN functions by decoupling the software from the hardware using virtualized network functions, referred to as virtual RAN (vRAN). This includes using network function virtualization (NFV) or containers to deploy CU and DU over bare metal servers such as an x86 server (e.g., commercial-off-the-shelf (COTS)) and operating network functions as software on a server platform. Figure 7 illustrates various vRAN deployment architectures using COTS hardware, including option 8, option 7x, and option 2 and 7.x splits.

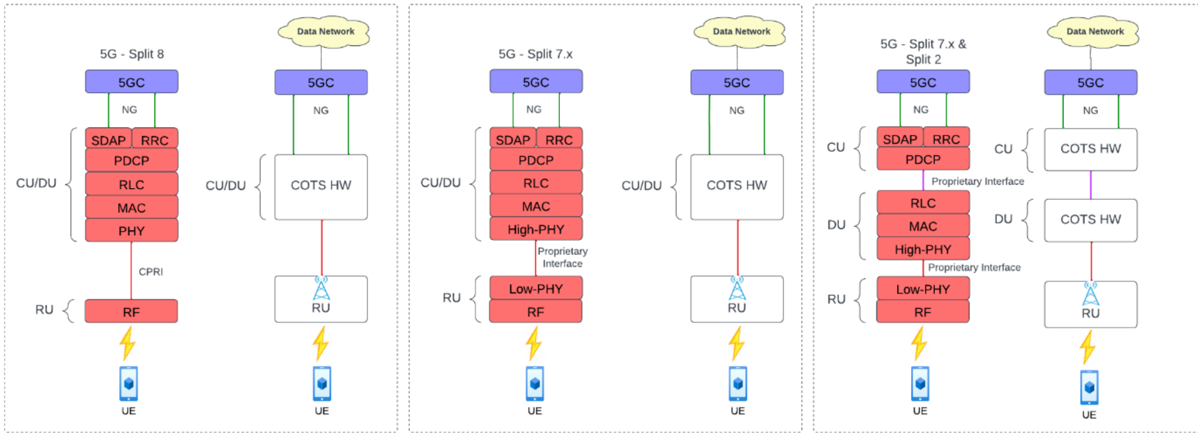


Figure 7. Various vRAN Deployment Architectures

3. Open RAN

Open RAN is the next shift in RAN architecture that builds upon RAN disaggregation and virtualization by adding the key elements of open interfaces, intelligence (i.e., automation, artificial intelligence, machine learning), and cloudification. When all these elements are integrated into an Open RAN architecture, it enables service providers the opportunity to create solutions for open, multi-vendor networks with enhanced flexibility and control.

Open RAN conforms to O-RAN Alliance specifications that build on the baseline functionality defined by 3GPP required for a complete and high-quality specification in order to guarantee multi-vendor inter-operability. This includes many of the 5G RAN functional split options, not including option 2, and gives the Open RAN ecosystem the flexibility to design any of these splits to meet deployment architectures defined by MNOs.

3.1 O-RAN ALLIANCE

The O-RAN Alliance has emerged as a prominent force in the Open RAN ecosystem, driving industry-wide collaboration and standardization efforts. By promoting openness, interoperability, and intelligence in RAN deployments the Alliance is reshaping the landscape of wireless networks, empowering operators with greater choice, flexibility, and innovation opportunities.

The O-RAN Alliance introduces the fronthaul interface, automation, and the RAN intelligent controller (RIC) to operate, optimize, and conduct configuration/performance management. There are several Working Groups (WGs) that address the interfaces, test cases, and specifications. Figure 8 illustrates the 3GPP defined interfaces and the O-RAN Alliance interfaces. O-RAN Alliance specifications are primarily based on 3GPP specifications and requirements.

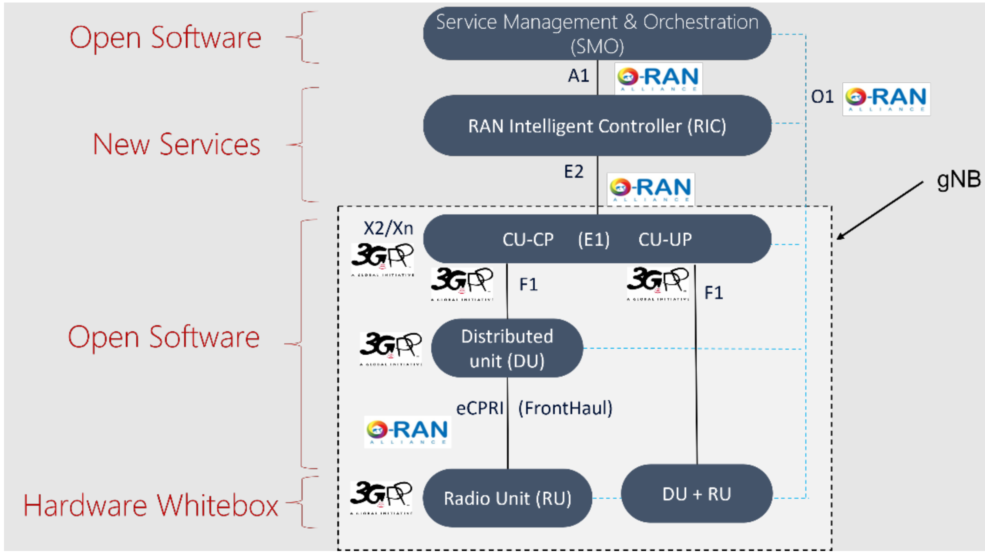


Figure 8. 3GPP and O-RAN Alliance coexistence

3.2 Open RAN Architecture

Open RAN logical architecture refers to the high-level design and organization of components within an Open RAN ecosystem. It defines the logical relationships, interfaces, and functionalities between different elements to enable interoperability, flexibility, and scalability. The Open RAN logical architecture is designed to decouple hardware and software, allowing for the integration of best-of-breed components from multiple vendors. The overall vision of Open RAN architecture is to utilize RAN components as a virtual software application capable of working on any bare metal hardware operated with orchestration and automation. This is accomplished with the key elements of virtualization, disaggregation, open interfaces, intelligence, and cloudification, which are foundational components to an Open RAN architecture.

At the core of the Open RAN logical architecture, as shown in Figure 9, is the concept of functional split, described previously, which separates the RAN functions into different components. These components typically include the RU, DU, CU, and Management and Orchestration (MANO) layer. The RU is responsible for radio signal transmission and reception, while the DU handles baseband processing and digital signal processing tasks. The CU centralizes functions such as scheduling, beamforming, and network optimization. The MANO layer oversees the management and orchestration of the entire Open RAN system, including resource allocation, configuration management, and service provisioning.

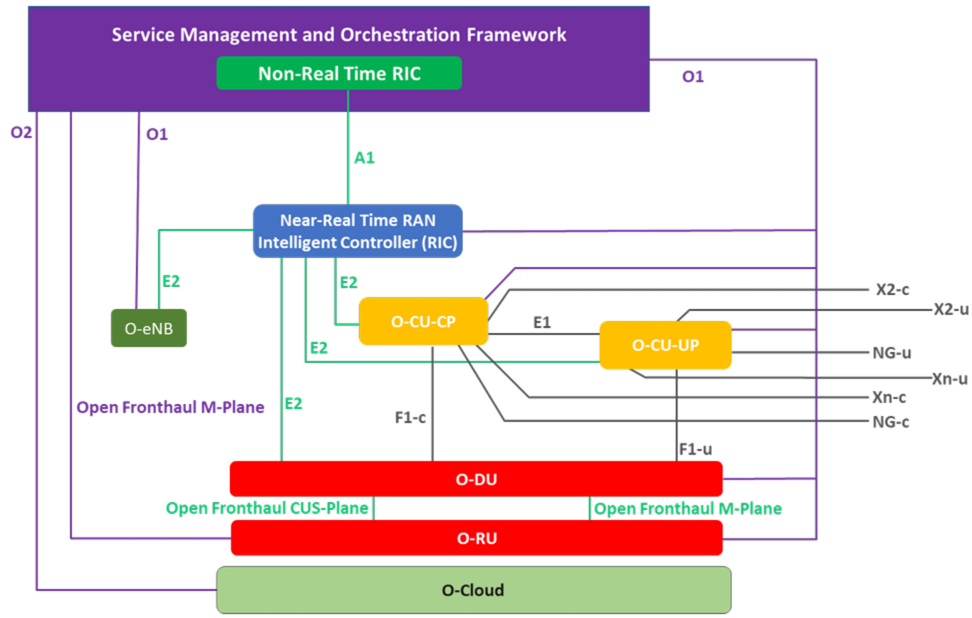


Figure 9. Logical Open RAN Architecture

Open interfaces and standardized protocols play a crucial role in the Open RAN logical architecture. These interfaces enable seamless communication and interoperability between different components from various vendors. By adopting open interfaces, Open RAN promotes vendor diversity, encourages competition, and reduces vendor lock-in. The standardized protocols ensure that the components can effectively communicate and exchange information, facilitating the dynamic allocation of resources and the efficient operation of the network.

Overall, the Open RAN logical architecture provides a blueprint for building open, flexible, and interoperable RAN solutions. It enables network operators to deploy and manage RAN components from different vendors, fostering innovation, reducing costs, and promoting a more competitive telecommunications ecosystem.

Cloudification

One key element to Open RAN is the adoption of Containerized Network Functions (CNFs) and the shift towards virtualization and Cloudification. The transition from Physical Network Functions (PNF) to Virtual Network Functions (VNF) to CNFs represents a significant evolution in network architecture and deployment models. Initially, traditional telecommunication networks relied on PNF, which involved dedicated hardware for each network function. However, the industry recognized the need for more flexibility, scalability, and cost-efficiency, leading to the adoption of VNFs. VNFs virtualized network functions, enabling them to run on standard servers and be dynamically instantiated or scaled as needed. This shift allowed operators to reduce hardware dependencies and achieve greater agility.

The subsequent transition from VNFs to CNFs further advances network virtualization and cloudification. CNFs leverage containerization technology, such as Docker or Kubernetes, to encapsulate network functions into lightweight, isolated containers. CNFs offer numerous benefits, including faster deployment times, efficient resource utilization, and easier management and orchestration. By embracing CNFs, operators can leverage the scalability and portability of containerization, enabling them to build cloud-native architectures and take full advantage of cloud-based infrastructure and services. This is illustrated in Figure 10.

Cloud RAN is yet another evolution in 5G RAN in that the hardware will be a containerized platform that will host RAN radio stacks as a CNF application. This further separates the software from the hardware.

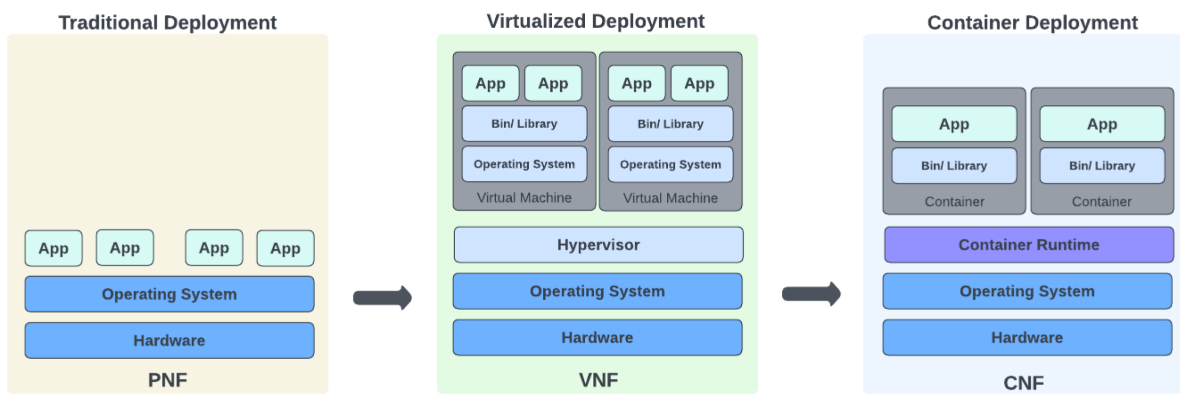


Figure 10. Traditional to Virtualized to Containerized Platforms

Open RAN has embraced the concept of CNF as part of its journey towards virtualization and cloudification. Open RAN aims to disaggregate and open up traditionally closed and proprietary network components, fostering interoperability and innovation. CNFs align well with the principles of Open RAN by enabling the deployment of flexible, scalable, and easily manageable network functions. By embracing containerization and cloud-native architectures, Open RAN networks can leverage the benefits of virtualization and drive the next generation of open and innovative telecommunications infrastructure.

3.3 Key Benefits

When fully integrated, Open RAN offers many key benefits that are critical to service providers' ability to deploy RAN architecture in a flexible, customized, open manner. Many of the key benefits and attributes are described below.

1. *Enhanced flexibility*: Open RAN enables multi-vendor interoperability, allowing network operators to choose hardware and software components from different vendors. This flexibility promotes innovation, competition, and prevents vendor lock-in.
2. *Cost reduction:* By decoupling hardware and software components, Open RAN reduces the dependency on proprietary equipment and enables the use of off-the-shelf, commodity hardware. This leads to cost savings in network deployment and maintenance.
3. *Improved scalability*: Open RAN architecture enables the deployment of networks in a more modular and scalable manner. Operators can easily add or remove network elements based on demand, optimizing network resources, and reducing capital expenditures.
4. *Accelerated innovation*: Open RAN encourages the development of new solutions by allowing different vendors to contribute and integrate their innovations into the network ecosystem. This fosters rapid development, improved feature sets, and faster time-to-market for new technologies.

5. *Increased vendor diversity:* Open RAN promotes a diverse vendor ecosystem by enabling the participation of smaller or niche vendors who may specialize in specific network components. This diversification helps prevent monopolies and encourages healthy competition.
6. *Interoperability and standardization*: Open RAN adheres to open standards and specifications, ensuring interoperability between different vendors' equipment. This facilitates seamless integration and compatibility between components, leading to more efficient and reliable network operations.
7. *Easier network optimization*: With Open RAN, operators have greater visibility and control over network performance. They can optimize specific network functions, such as radio resource management, to improve efficiency, capacity, and overall user experience.
8. *Rapid deployment and upgrades*: Open RAN simplifies network deployment and upgrade processes by enabling the use of software-defined approaches. Operators can remotely deploy software updates and new features, minimizing service disruptions and reducing operational costs.
9. *Enhanced network customization:* Open RAN allows operators to customize network features and functionalities based on their specific requirements. This customization capability enables tailored solutions for different use cases, such as private networks or IoT applications.
10. *New Technology Interworkin*g: Open RAN facilitates integration with emerging technologies such as cloud computing, artificial intelligence, and edge computing. This integration enables new methods for network optimization, intelligent traffic management, and enhanced user experiences.

3.4 Deployment Scenarios

Open RAN architecture coupled with 5G RAN split options provide flexibility to the operator to customize an architecture to meet various deployment scenarios with minor enhancements to the RAN. The list below describes some common Open RAN deployment scenarios:

1. *Macro Cells*: Open RAN can be deployed in macro cell environments, which typically cover larger geographic areas and provide wide-area coverage. By adopting Open RAN, operators can introduce flexibility and vendor interoperability in their macro cell networks, enabling the integration of different hardware and software components from various vendors.

2. *Small Cells*: Open RAN can also be used in small cell deployments. Small cells are low-power, short-range base stations that enhance network capacity and coverage in densely populated areas or indoor environments. Open RAN allows for the disaggregation of small cell hardware and software, promoting interoperability and enabling operators to choose the best components for their specific needs.

3. *Private 5G Networks*: Open RAN can facilitate the deployment of private 5G networks. These networks are typically used by enterprises, industries, or government entities for dedicated connectivity and specific use cases like industrial automation, smart cities, or critical infrastructure. Open RAN provides the flexibility to customize and optimize network solutions for private deployments, enabling organizations to tailor their networks to their unique requirements.

4. *Rural Connectivity*: Open RAN can play a crucial role in expanding connectivity in rural or underserved areas. Traditional network equipment can be expensive and challenging to deploy in such regions. Open RAN offers a more cost-effective and flexible solution, allowing operators to leverage a mix of hardware and software components from different vendors to build and operate networks in rural areas.
5. *Neutral Host Networks*: Open RAN can support neutral host network deployments. Neutral hosts provide shared infrastructure and services that enable multiple operators or service providers to utilize the same network infrastructure. Open RAN facilitates the integration of multiple operators' equipment and allows for interoperability, enabling efficient sharing of network resources and reducing deployment costs.
6. *Network Densification*: Open RAN can assist in network densification efforts by deploying additional base stations in high-traffic areas to increase capacity and improve user experience. Open RAN's flexibility and interoperability enable operators to deploy cost-effective and efficient solutions for network densification, accommodating growing data demands and enhancing network performance.

The flexibility, interoperability, and cost efficiencies offered by Open RAN make it a compelling choice for various network environments, helping operators address specific challenges and deliver improved connectivity and services.

4. Open RAN Ecosystem Activity

The Open RAN ecosystem is fluid with a broad range of industry activity that includes commercial MNO deployments, industry testbeds and trials, and government policy and investment. These activities demonstrate proof-of-concept and end-to-end validation of Open RAN subsystems and systems and show the progress towards a full set of Open RAN features. This section provides highlights of some examples of industry activities.

4.1 Global Mobile Network Operator Activity

Several global MNOs have deployed greenfield and brownfield commercial Open RAN networks while others have made public announcements of field trials, partnerships, and commitments to Open RAN deployments. This section highlights representative examples of these industry activities and addresses the progress and level of fully integrated Open RAN elements in each.

Greenfield Deployments

Two MNOs lead by deploying the industry's first greenfield Open RAN commercial networks. The first, Rakuten, a Japanese MNO[2], integrated Open RAN elements into commercially launched Open RAN 4G and 5G networks using disaggregated, virtualized RAN on a cloud native architecture using accelerated automation and intelligence. The network offers virtualized Open RAN software that can be implemented on any COTS component. While this network has successfully proven several Open RAN elements, it has yet to prove fully integrated Open RAN across multi-vendors on a cloud native platform with a fully developed RIC.

[2] https://symphony.rakuten.com/open-ran

The second, DISH Wireless, a US MNO, integrated Open RAN elements into a commercially launched Open RAN 5G Standalone (SA) network that includes disaggregated, virtualized features on a cloud native architecture using automation and intelligence[3]. While this network succeeded in utilizing these Open RAN elements, it is still validating the remainder of the Open RAN elements such as open interfaces, using commercial-off-the-shelf products, and multi-vendor interoperability with a fully developed RIC, at scale and with reliability.

Brownfield Deployments

A leading Japanese MNO[4] [5], DoCoMo, integrated Open RAN elements into their existing commercial 4G and 5G network deployments using disaggregation, virtualized, and intelligent (i.e., MANO) features with multiple vendors, however it uses purpose-built hardware and partially compliant Open RAN interfaces with partnered vendors within its network. DoCoMo announced that their continued brownfield deployment efforts will include development of software onto COTS hardware, fully compliant open interfaces, cloud native architecture, and continued automation and application development of the SMO/RIC.

A leading US MNO, Verizon, deployed a disaggregated and virtualized 5G RAN on COTS hardware on its own cloud platform using automation and is working towards development of complaint open interface between Open RAN elements.[6] [7] Their goal is to use Open RAN architecture in parts of the network serving dense urban areas.

Continued Commitment by MNOs

Many of the world's largest operators have made public announcements of field trials, partnerships, and commitments to Open RAN deployments.

A leading European MNO, Vodafone, deployed a brownfield Open RAN network trial[8] that utilizes a disaggregated RAN with virtualized software and Open RAN compliant RUs across its trial 4G and 5G network[9]. The RUs support low and mid band spectrum and include massive MIMO capability. Vodafone's initiative is to use Open RAN in at least 2,500 sites by the end of 2027[10].

In 2021, a group of five leading European MNOs (Vodafone, Deutsche Telekom (DT), Orange, Telefónica, and TIM) signed a Memorandum of Understanding (MoU) and formed the Open RAN MoU Group within TIP. The group's focus is to develop and define Open RAN solutions to further implementation of Open RAN technologies and networks. The formation of the group demonstrates the MNOs' commitment to Open RAN deployment and addresses collaborative Open RAN technical priorities in multiple Releases[11]. Release 1 (2021) focused on the main scenarios and technical requirements for each of the building blocks of a multi-vendor RAN. Release 2 (2022) mainly focused on intelligence, orchestration, transport, and cloud infrastructure, addressing energy efficiency goals and targets to support sustainable Open RAN. Release 3 (2023) primarily focused on developing further

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[3] https://about.dish.com/2023-02-23-DISH-Wireless-Expands-Cloud-Native-Open-RAN-Network-With-Mavenir-Open-vRAN-Software-Solutions
[4] https://www.docomo.ne.jp/english/info/media_center/pr/2019/0918_00.html
[5] Open_RAN Docomo.pdf
[6] https://www.mobileworldlive.com/featured-content/home-banner/verizon-gears-up-for-open-ran-field-trials/
[7] https://news.samsung.com/us/samsung-verizon-charge-ahead-with-vran/
[8] https://www.vodafone.com/about-vodafone/what-we-do/technology/open-ran
[9] https://news.samsung.com/global/vodafone-and-samsung-begin-mass-open-ran-rollout-across-the-united-kingdom
[10] https://www.sdxcentral.com/articles/news/samsung-strikes-5g-vran-open-ran-deal-with-vodafone/2023/09/
[11] https://telecominfraproject.com/openran-mou-group/

requirements on Service Management and Orchestration (SMO) and RIC and enhancements to security, cloud infrastructure, O-CU/O-DU, and O-RU.

A leading European MNO, Deutsche Telekom, completed an 'Open RAN Town' field trial[12] with several vendors to investigate the development, capability, and operations of a fully integrated multi-vendor Open RAN solution based on O-RAN Alliance specifications. The trial resulted in a successful integrated Open RAN solution with key learnings of various aspects of Open RAN that include maturity, integration, scalability, security, and energy efficiency.

4.2 Industry Test Beds

There are several leading industry test beds that are instrumental in advancing and testing proof of concept and compliance to Open RAN architecture, which include OTICs, TIP OpenRAN, and SONIC labs.

Open Testing and Integration Centres (OTICs)

The O-RAN Alliance established OTICs[13] which are vendor-independent, open, and neutral lab environments that support Open RAN ecosystem development to advance the adoption of Open RAN. There are 15 globally authorized OTICs, one of which includes CableLabs/Kyrio as the first established OTIC in North America.

OTICs provide various levels of conformance, interoperability, and end-to-end testing (e2e) of Open RAN components and subsystems against O-RAN Alliance interface specifications and award O-RAN Alliance certificates and badging, which include:

- Conformance testing: OTICs can test the conformity of RAN equipment to O-RAN Alliance interface specifications.
- Interoperability testing: OTICs can test the interoperability of RAN equipment from different vendors (or the same vendor) using O-RAN Alliance interface specifications.
- Performance testing: OTICs can test the performance of RAN equipment under different load conditions.
- Security testing: OTICs can test the security of RAN equipment against known vulnerabilities.

As of this writing, twelve badges have been awarded across six different vendors for open fronthaul conformance, interoperability, and e2e validation, eight of which have been awarded in 2023. This demonstrates that open fronthaul is commercially available and the maturity of Open RAN is gaining momentum.

OTICs also host periodic Global Plugfests[14], co-hosted by the O-RAN Alliance, to showcase proof of concept, interoperability, or end-to-end validation of Open RAN solutions. Plugfests demonstrate many levels of validation of Open RAN solutions with multiple vendors.

TIP Community Labs

TIP Community Labs were established by various players in the ecosystem (i.e., operators, vendors, academia) to support the development, testing, and deployment of open, disaggregated Open RAN

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[12] https://www.telekom.com/en/company/details/bundled-in-a-white-book-learnings-from-o-ran-town-1026846
[13] https://www.o-ran.org/testing-integration#learn-otic
[14] https://plugfestvirtualshowcase.o-ran.org/2023/SPRING

solutions[15]. There are 14 TIP Community Labs worldwide, each having their own set of test equipment and specialized lab focus with industry partners. TIP developed their own certification process called 'Open RAN System Certification process (SCOPE)' that is complementary to the O-RAN Alliance certification process. It builds on O-RAN Alliance certification and test plans and offered at a TIP-accredited Open RAN system certification lab that is focused on pre-launch validation and post-launch regression and release upgrade validation.

SONIC Labs

The United Kingdom (UK) developed the SmartRAN Open Network Interoperability Centre (SONIC) Labs as an independent lab to host the development of Open RAN solutions through Digital Catapult[16], a company funded by the UK Department for Science, Innovation and Technology (DSIT), Department of Culture Media Sport (DCMS), and Ofcom.

SONIC Labs completed two phases of interoperability testing with multiple Open RAN vendors. The first phase, SONIC-1, was an initiative to conduct end-to-end testing of Open RAN solutions with multiple vendors across three separate field testbeds. The goals of SONIC-2 are to continue integration, multi-vendor interoperability of Open RAN solutions in indoor and outdoor environments, encourage innovation towards quicker deployment, and economic study.

4.3 Government Policy and Investment

Countries across the globe, including the United Kingdom, United States, Germany, Canada, Australia, India, South Korea, and Singapore are establishing policies and making available funding to the Open RAN ecosystem to advance the technology, development, and technology of Open RAN. Several governments generally view the RAN infrastructure vendor supply chain as an oligopoly and consider Open RAN as an economic, security, and supply chain issue, not a technical issue. The intent of many of the government programs is to de-risk the vendor oligopoly and supply chain and enable more resilient and secure networks.

United Kingdom

The UK DCMS announced its '5G Supply Chain Diversification Strategy'[17] in 2020 that consists of three focus areas: (1) supporting incumbent suppliers, (2) attracting new suppliers into the UK market, and (3) accelerating the development and deployment of open-interface solutions. It is backed by a £250 million investment in the project, which is highly focused on the development of Open RAN solutions.

United States

The United States government views mobile network infrastructure suppliers consisting of closed source software and hardware with proprietary solutions with vendor-lock and few choices to operators and subject to security and supply chain concerns. To overcome this vendor-lock, the National Telecommunications and Information Administration's Institute for Telecommunication Sciences (NTIA/ITS) in collaboration with the Department of Defense Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) created a multi-vendor interoperability event called the '5G

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[15] https://telecominfraproject.com/clabs/
[16] https://www.digicatapult.org.uk/about/press-releases/post/digital-catapult-and-ofcom-unveil-first-of-its-kind-open-ran-testing-facilities-in-the-uk/
[17] https://www.gov.uk/government/publications/5g-supply-chain-diversification-strategy/5g-supply-chain-diversification-strategy

Challenge' to influence the adoption of Open RAN solutions over a two-year timeframe (2022 and 2023).[18] The 5G Challenge included a total of $10 million in prize awards to contestants that demonstrate compliance to various levels of conformance, interoperability, performance, and reliability.

To further develop wireless innovation, promote competition, and strengthen supply chain resilience, Congress created the Public Wireless Supply Chain Innovation Fund[19], a $1.5 billion grant program. The NTIA is leading the implementation of the Innovation Fund and issued the first grants of the ten-year program in August 2023.[20]

Singapore

Singapore's Infocomm Media Development Authority (IMDA) in partnership with the National Research Foundation, Singapore (NRF) created a S$70 million Future Communications R&D Programme (FCP) that built an OTIC lab at the Singapore University of Technology and Design. The government investment is to promote the technological capabilities of Singapore and support the global Open RAN ecosystem.[21]

Germany

The German Federal Ministry for Digital and Transport (BMDV) has invested €17 million funding to the i14y Lab in Berlin[22]. The i14y Lab is an O-RAN Alliance OTIC that hosts Plugfests to validate the technical readiness of individual vendor solutions and explore multi-vendor interoperability in new or refined test scenarios. The i14y Lab is a joint effort with Deutsche Telekom, Vodafone, and Telefonica along with some of the vendor community to focus on test and integration of disaggregated network solutions.

Coordinated Efforts by Governments

UK, US, Canada and Australia

The UK, US, Canada, and Australia released a 'Joint statement on telecommunications supplier diversity'[23] that states a joint commitment to "ensuring the security and resilience of our telecommunications networks, including by fostering a diverse supply chain and influencing the development of future telecommunications technologies such as 6G. Collectively, we recognize that open and interoperable architectures are one way of creating a more open, diverse and innovative market."

US and India

The US and India share a commitment to "a vision of secure and trusted telecommunications, resilient supply chains, and global digital inclusion." The countries committed to Joint Task Forces focused on Open RAN, including an Open RAN field trial in India.[24]

[18] https://5gchallenge.ntia.gov/
[19] https://www.ntia.gov/page/innovation-fund
[20] https://www.ntia.gov/page/innovation-fund/grant-programs/notice-of-funding-opportunity
[21] https://www.sutd.edu.sg/Research/Research-News/2023/2/south-east-Asia-first-O-RAN-Open-testing-centre
[22] https://www.i14y-lab.com/
[23] https://www.gov.uk/government/publications/joint-statement-between-the-united-kingdom-australia-canada-and-the-united-states-of-america-on-telecommunications-supplier-diversity/joint-statement-on-telecommunications-supplier-diversity
[24] https://www.whitehouse.gov/briefing-room/statements-releases/2023/09/08/joint-statement-from-india-and-the-united-states/

US, South Korea, and Japan

The leaders of the US, South Korea and Japan committed to bolstering trilateral collaborative research and development in science, technology engineering, and mathematics, including Open RAN.[25]

These recent commitments and investments by many governments demonstrate the growing importance of Open RAN across the globe.

5. Multi-Vendor Open RAN integration at CableLabs

CableLabs and its Kyrio subsidiary have a strong history of holding vendor agnostic, neutral host interoperability events for the industry. Starting with interoperability events for DOCSIS technologies, CableLabs now hosts events for optical technologies, Wi-Fi technologies, Citizens Broadband Radio Service (CBRS) and Spectrum Access System (SAS) interoperability for 3GPP technologies, and most recently Open RAN.

The key to accelerating Open RAN adoption is to demonstrate comparable performance of an integrated 5G RAN with a multi-vendor setup utilizing a disaggregated, virtualized RAN. CableLabs and Kyrio were the host lab for the 5G Challenge in 2022 and 2023 and provided a state-of-the-art test lab, expert staff in wireless networks and Open RAN, and performed all of the testing of contestant's systems. In addition, CableLabs and Kyrio provided expertise to NTIA-ITS and DoD when designing the challenge, the rules, and the grading process. CableLabs and Kyrio also became the first established OTIC Lab in North America and hosted several O-RAN Alliance Plugfests. From these experiences, CableLabs is recognized as an industry leader in the Open RAN ecosystem as system integrators, independent and neutral host of a fully featured Open RAN test lab, Open RAN subsystem and system test experts, and contributors to Standards Development Organizations (SDOs) (i.e., O-RAN Alliance, TIP, 3GPP). Our labs and expertise help industry develop the building blocks required to accelerate the adoption of Open RAN. This section provides an overview of the lab, completed tests and results, observations, and lessons learned from these Open RAN activities.

5.1. Lab Overview

The Open RAN Interoperability lab is a virtual lab that is part of CableLabs 10G lab and consists of multiple racks housing servers and test equipment that includes a 5G core emulator, User Equipment (UE) emulators, CU, DU, and RU emulators, fronthaul analyzer, Radio Frequency (RF) spectrum analyzers, RF vector signal analyzers and generators, a UE diagnostics tool, a commercial 5G SA core, and two 5G vRANs, as shown in Figure 11.

[25] https://www.whitehouse.gov/briefing-room/statements-releases/2023/08/18/the-spirit-of-camp-david-joint-statement-of-japan-the-republic-of-korea-and-the-united-states/

Figure 11. CableLabs/Kyrio Test Lab Facilities

The lab test equipment offers a full set of Open RAN features from two different Open RAN test emulator vendors, Viavi and Keysight, that demonstrate compliance to 3GPP and O-RAN Alliance specifications as well as development and proof of concept activities. This configuration provides flexibility and capacity in testing by offering two ‘swim lanes’ of simultaneous testing to support multiple vendors.

As shown in Figure 12, the test equipment is configured to support (1) standalone subsystems for conformance and interface testing, (2) paired subsystems for interoperability (IOT) testing, and (3) end-to-end integration, interoperability, functional, and performance testing.

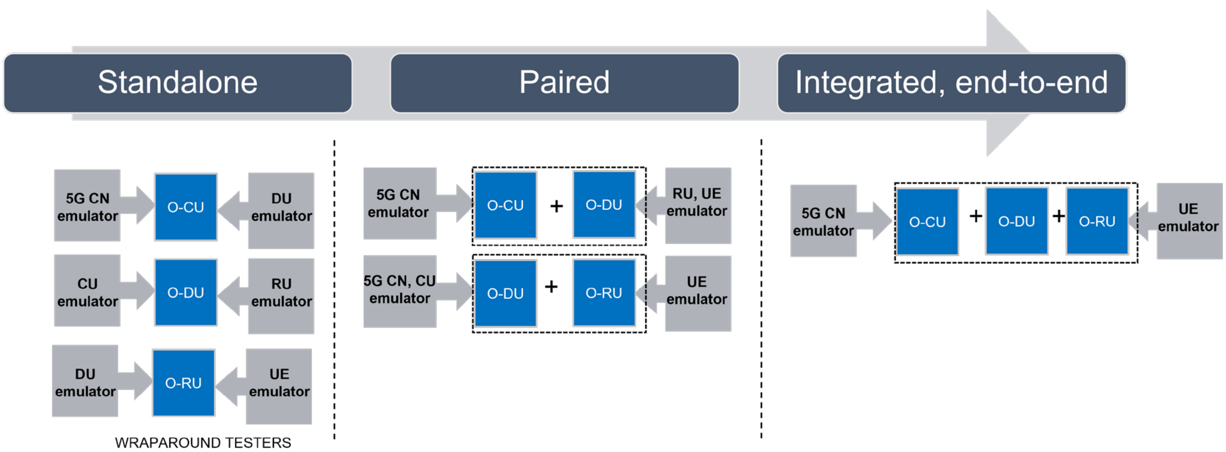

Figure 12. Open RAN subsystem/system test configurations

As shown in Figure 13, the lab supports the entire range of OTIC certification and badging tests and testing of all the O-RAN Alliance interfaces, conformance, IOT, and e2e interoperability across single and paired vendors in addition to multiple Open RAN vendors. The lab capabilities are used as a framework for Open RAN development and interoperability testing beyond the 5G Challenge and OTIC Plugfests, including internal R&D projects and requests from Open RAN vendors and MNOs.

	Subsystem	IOT	E2E System	Functional	Performance	Certification	Badging
O-RU	■	■	■	■	■	■	■
FHGW			□	□	□		
O-DU	■	■	■	■	■		■
O-CU-CP	■	■	■	■	■		■
O-CU-UP	■	■	■	■	■		■
O-CU-CP & O-CU-UP	■	■	■	■	■		■
O-RU & O-DU	■	■	■	■	■		■
O-DU & O-CU-CP & O-CU-UP	■	■	■	■	■		■

	RF	OFH-C	OFH-U	OFH-S	OFH-M	F1-C	F1-U	Xn-C	Xn-U	E1	NG-C	NG-U
O-RU	■	■	■	■	■							
FHGW		■	■	■	■							
O-DU		■	■	■	■	■	■					
O-CU-CP						■		■		■	■	
O-CU-UP							■		■	■		■
O-CU-CP & O-CU-UP						■	■	■	■		■	■
O-RU & O-DU	■	■	■	■	■	■	■					
O-DU & O-CU-CP & O-CU-UP		■	■	■	■			■	■		■	■
Transport xHAUL		□	□	□	□	■	■	■	■	□	□	□

Figure 13. CableLabs/Kyrio OTIC test and certification capabilities

5.2. Industry Test Results

The 2022 5G Challenge successfully demonstrated multi-vendor end-to-end interoperability across an Open RAN system comprised of three different 'cold' vendors (never been integrated with each other in the past) and conducted data sessions using various protocols (UDP, TCP, RTP, streaming video). This was accomplished in a 5-week period (compared to several months in other industry labs) which demonstrated the maturity and variety of available Open RAN vendors in the ecosystem. Details of the findings are described in the NTIA Technical Memorandum 23-568: 5G Challenge Preliminary Event: Evaluating Modular, Interoperable, Multi-Vendor, Open RAN Solutions[26].

The 2023 5G Challenge demonstrated multi-vendor end-to-end interoperability with four pairs of Open RAN systems (i.e., CU/DU and RU) with seven different vendors conducting data sessions using various protocols (UDP, TCP, RTP, streaming video), traffic loading, and stability in varying RF conditions. Two pairs of multi-vendor Open RAN systems continued on to demonstrate mobile handover (Xn and NG) between the two different Open RAN gNBs, which is known to be the industry's first. These functional, performance, loading, stress, and reliability tests demonstrate the maturity and variety of available Open RAN vendors in the ecosystem.

CableLabs/Kyrio OTIC Plugfests[27] followed a similar track by conducting conformance, interface, and e2e interoperability tests with nine different vendors. Tests included multi-vendor e2e interoperability (mobility, performance, load, QoS), standalone conformance, RIC (xApp, energy savings), and paired integration. For several years, over 25 different Open RAN vendors testing in 15 different OTIC labs have been conducting proof-of-concept, interface validation, paired integration, e2e interoperability, and RIC

[26] NTIA Technical Memorandum 23-568: 5G Challenge Preliminary Event: Evaluating Modular, Interoperable, Multi-Vendor, Open RAN Solutions
[27] https://plugfestvirtualshowcase.o-ran.org/2023/O-RAN_Global_PlugFest_hosted_by_University_of_New_Hampshire

testing. This level of activity, including a recent uptick, demonstrates the progress and maturity of the Open RAN ecosystem[28].

5.2.1. Standalone Tests

As shown in Figure 14, wraparound testers are used to conduct conformance and interface testing with a single CU, DU, or RU as the Device Under Test (DUT). Wraparound testers are used to validate compliance to 3GPP and O-RAN Alliance specifications at an interface level by emulating all the other components encompassing the DUT. The goal is to validate the basic functionality against the specifications with regards to the messages and Information Elements (IEs) that are carried across the interfaces supported by the subsystem. O-RAN Alliance Work Group 4 (WG4) and Work Group 5 (WG5) specifications and test cases are used as the baseline for tests and reference with the lab setup shown in Figure 14.

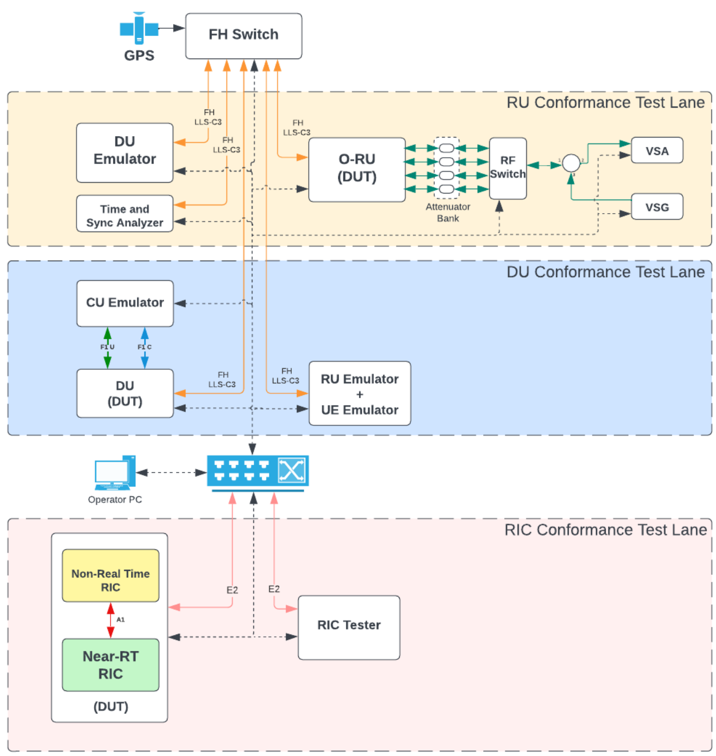

Figure 14. CableLabs/Kyrio lab setup for standalone wraparound tests

[28] https://www.o-ran.org/what-we-do

5.2.2. *End-to-end Integration*

As shown in Figure 15, Core and UE emulators are used to conduct end-to-end integration testing with paired Open RAN subsystems and systems. O-RAN Alliance WG5 and Test and Integration Focus Work Group (TIFG) specifications and test cases are used as the baseline for tests and reference with the lab setup shown in Figure 15. Objectives of the multi-vendor sub-system tests are summarized below:

- Interoperability and baseline functionality to successfully set up an e2e network that could pass different data traffic types such as TCP, UDP, FTP, ICMP, and RTP.
- e2e network performance with a multi-vendor setup that includes single UE stationary and mobile uni-and bi-directional throughputs in different radio conditions, multiple UE aggregated cell throughput, e2e network loading, stability, and reliability using different traffic models to simulate real world scenarios.
- Mobility scenarios for connected mode mobility and idle mode reselection for both intra and inter frequency over N2 and Xn interfaces.

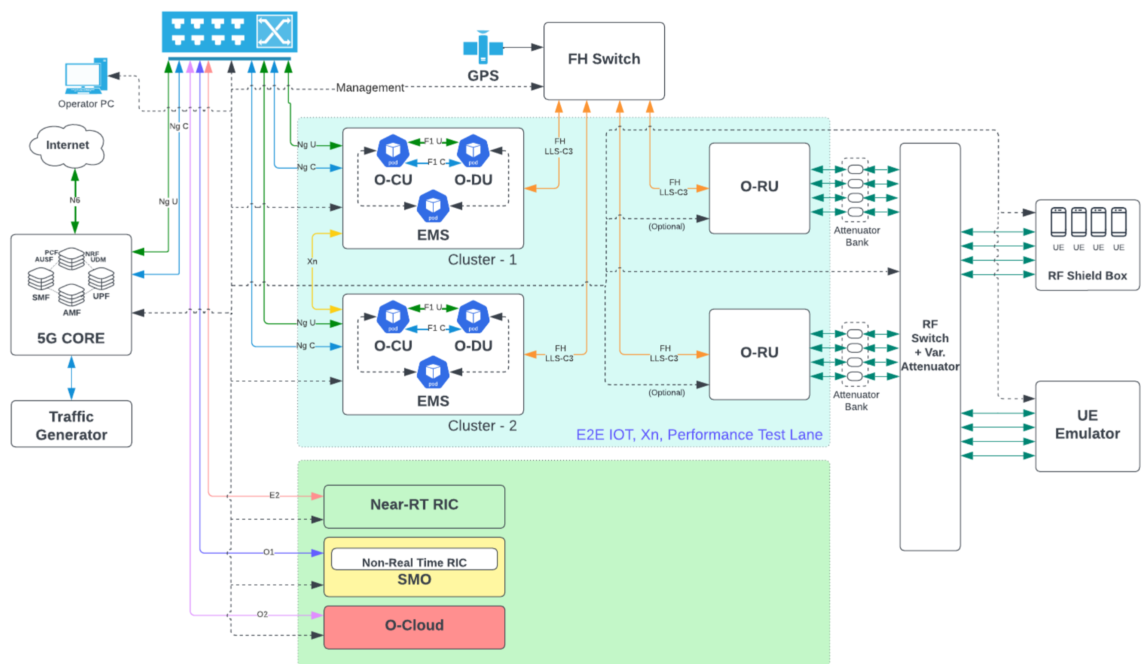

Figure 15. CableLabs/Kyrio lab setup for e2e integration

5.3. Observations

This section provides a summary of observations from Open RAN test activities at CableLabs to date.

Baseline Functionality - 100% of vendors successfully validated the 3GPP defined messaging for 5G system procedures across a multi-vendor e2e setup.
All the vendors successfully demonstrated the base functionality needed to establish an e2e setup that could allow the UEs to register/deregister, establish PDU sessions, perform service request and paging procedures, re-establish network connection post RLF, and perform state transitions. The system procedures were thoroughly validated for messaging and IEs exchanged between the multi-vendor

disaggregated RAN subsystems. Though certain challenges arose when the subsystems coming from different vendors were compliant to different specification releases or versions (within a release) and when vendors had different implementations considering the flexibility allowed within the specifications, the obstacles were overcome with collaboration and the adaptive mindset of the vendors.

Performance - 80% of vendors achieved peak throughputs (close to expected theoretical) and acceptable performance at cell edge across the multi-vendor e2e setup.
This was one of the key evaluation metrics to showcase if Open RAN multi-vendor disaggregated RAN could have a comparable performance when measured against the monolithic single vendor RAN. Leveraging the ORAN TIFG specification, the performance was evaluated with regards to throughput in both uplink and downlink for different traffic types (e.g., TCP, UPD, FTP) with UEs at different radio conditions. The performance was evaluated with stationary/mobility scenarios and with single/multiple UE(s). Key Performance Indicators such as RTT (for ICMP traffic), Jitter (for RTP traffic), and MOS score (for video traffic) were evaluated to complete a more thorough assessment of network performance.

Handover - 100% of vendors demonstrated mobility over Xn and N2 across the multi-vendor e2e setup.
The one aspect that has not been tested or vetted by the industry to date is the handovers across multi-vendor setups. The Xn is traditionally a closed interface with significant implementation differences across vendors and customized behavior tailored towards specific operator deployments. A successful demonstration of Xn and N2 connected mode mobility (handovers) and idle mode mobility (cell reselection) for both intra and inter-frequency scenarios across a multi-vendor setup was completed.

Stability - 70% of vendors sustained multiple UE connections across the multi-vendor e2e setup without dropping a call for long duration test runs.
Though the stability testing is done in a controlled lab environment, taking interference from neighboring networks out of the equation, simulating multiple UEs at different radio conditions, loading the network, and ensuring the stability over long durations, demonstrates the ability of the Open RAN multi-network setup to sustain in real deployments.

Reliability - 50% of vendors with the ability for multiple UEs in different RF conditions to run traffic across the multi-vendor e2e setup.
Though the reliability testing was not done on a cluster of nodes with thousands of UEs simultaneously connecting to the network and encountering interference from the neighboring deployments and environmental factors, as would be the case in real-world deployments, the reliability testing allowed us to run different traffic models and test the ability of the multi-vendor setup to sustain the network connectivity and performance offering some insights into how reliable the e2e setup is.

A limited number of vendors bring a software-only solution utilizing the bare metal servers
More than 90% of the vendors prefer to bring in their own hardware along with their software solutions. The limited integration time allowed in plugfests or the 5G Challenge is one of the prime reasons for vendors opting to ship their own hardware. This is also an indication of the software and hardware inter-dependency (software solutions may need a specific type of server, CPU version, etc.)

A majority of vendors required hardware accelerators
More than 50% of the vendors require hardware accelerators to boost the performance of the vendor's system to the expected level.

Average integration time for a vendor to integrate with test platform - 1 week (5 business days)

Assuming vendors ship hardware in a timely manner or have the software ready to install on the bare metal servers at the test lab, all the vendors were able to integrate with the test platforms within five business days. This also considers the readiness of the test lab with regards to the test setup, networking (IP address and VLAN assignments), power needs, and required cabling and SFPs in place.

Average integration time for multi-vendor integration - 1 week (5 business days)
With the same consideration mentioned for integration with a test platform, the multi-vendor integration took the same amount of time, indicating the integration process should not take longer if the best practices are followed with the required system integration expertise available at the test lab. The only additional factor in the case of multi-vendor integration is parameter configuration alignment to be able to successfully communicate over the spec-defined interfaces. While in case of integration with the test platform, the test platform can always be aligned to adapt to the vendor configuration, in case of multi-vendor integration a handshake is required to agree on specific parameters which can take longer in certain cases when the vendor solutions are not flexible to adapt such as having hard coded parameters that require software patch to align with the other sub-systems during integration.

5.4 Lessons Learned

As Open RAN continues to gain traction and maturity in CableLabs and similar labs worldwide, the following were general lessons learned:

- O-RAN Alliance test plans/cases and specifications are a solid foundation to support development efforts and demonstrate subsystem/system validation. Creating a common test plan, requirements, and features used by all industry labs would help operators adopt Open RAN faster.
- Plugfests and interoperability labs provide a valuable environment and means for subsystem/system development and interoperability.
- Achieving alignment of implementation/interpretation of 3GPP/O-RAN Alliance specifications between vendor subsystem and test emulators is a common challenge.
- As Open RAN continues to mature, developing certified trusted solutions for operators that include features and requirements for a common deployment profile will help accelerate Open RAN adoption.

6. Open RAN Transition

As MNOs continue to build out 5G networks there are many key elements of RAN architecture to consider as they evaluate deployment approaches, purchasing cycles, business strategy, customer needs, and deployment scenarios. As Open RAN continues to mature, the path of MNO RAN buildout and growth strategy may overlap with the developments in Open RAN architecture. This section proposes a transition approach from vRAN to a fully integrated Open RAN architecture.

6.1. Transition from vRAN to Open RAN

The transition from vRAN to Open RAN can be characterized by evaluation indicators, several of which are summarized below.

1. *Virtualization of Baseband Processing:* In vRAN, baseband processing functions are virtualized and run on standard servers or cloud infrastructure. However, in Open RAN, the focus shifts to disaggregating the RAN components, allowing for multi-vendor interoperability and greater flexibility.

2. *Interoperability and Standardization*: Open RAN emphasizes interoperability between different vendors' hardware and software components. This involves adopting open standards and

interfaces such as O-RAN Alliance specifications. The transition from vRAN to Open RAN involves the adoption and implementation of these standardized interfaces.

3. *Multi-vendor RAN Deploymen*t: One of the key characteristics of Open RAN is the ability to mix and match equipment from different vendors. This allows operators to select best-of-breed solutions and avoid vendor lock-in. The transition from vRAN to Open RAN involves enabling multi-vendor deployments and ensuring compatibility between various vendors' equipment.
4. *Cloud-Native Architecture:* While vRAN leverages virtualization, Open RAN takes it a step further by adopting cloud-native architecture principles. Open RAN solutions are designed to be highly scalable, flexible, and capable of running on cloud platforms. Transitioning from vRAN to Open RAN involves embracing cloud-native architectures and containerization techniques.
5. *Open Interfaces and APIs*: Open RAN relies on open interfaces and APIs (Application Programming Interfaces) to enable interoperability and facilitate the integration of different RAN components. These interfaces and APIs allow for easier customization, innovation, and the introduction of new functionalities. The transition from vRAN to Open RAN involves implementing and utilizing open interfaces and APIs.

The transition from vRAN to Open RAN is an ongoing process, and the significance of these indicators may vary depending on the specific context and timeline of an MNO’s implementation.

6.2 Open RAN Transition Approach

A transitional approach to Open RAN architecture is illustrated in the diagram in Figure 16. It is based on the five key elements of Open RAN architecture, namely, Virtualization (V), Disaggregation (D), Open Interface (O), Cloudification (C) and Intelligence (I). These elements are depicted as a 5-piece ‘element dial’ that is used as a reference during transition and are arranged in a matrix-like structure, with hardware depicted along the horizontal path and software along the vertical path.

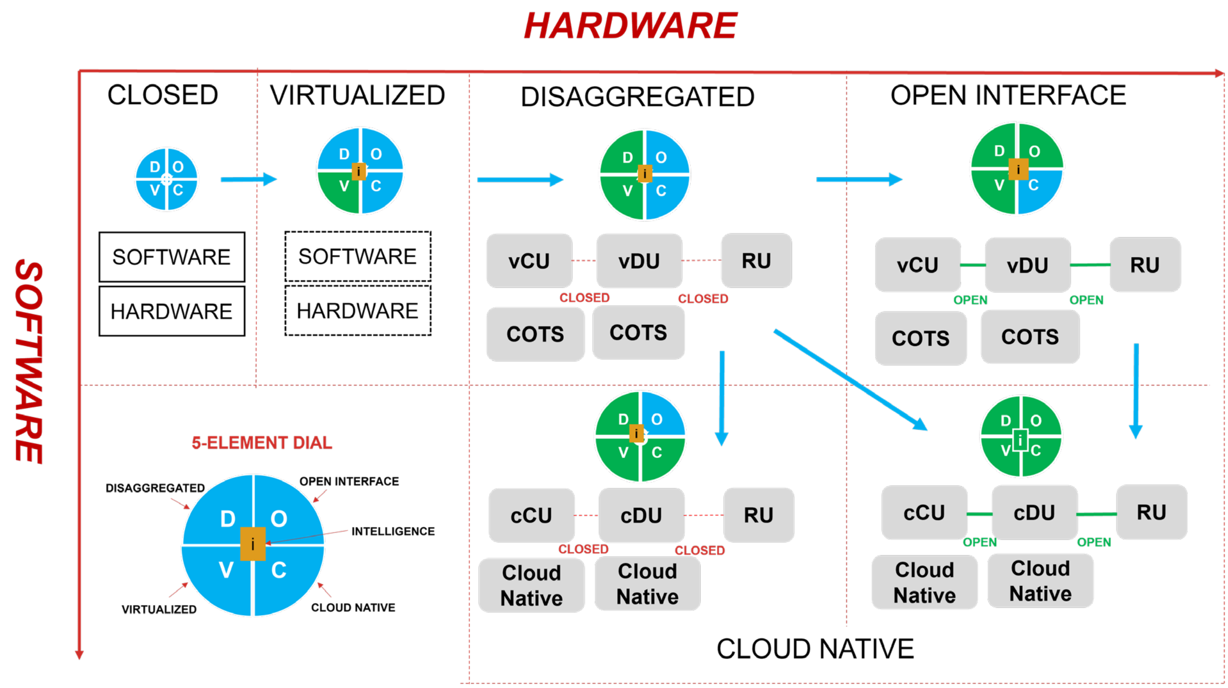

Figure 16. Open RAN transition approach

The transition starts with a closed, proprietary RAN with no Open RAN elements and leads to an outcome with all five elements. There are three main paths leading to the 5-element outcome with each path adding an element to the Open RAN architecture as it is built. As an element is added to the architecture, its color changes to green on the ‘element dial’. The paths can follow a hardware or software progression. The intelligence element (i.e., automation, orchestration) is included at the center of the ‘element dial’ and remains the same color until the 5-element outcome is realized since its implementation is independent of the other elements which are more architecture components of Open RAN. While the intelligence element is a key part of each transitional architecture, its composition can vary as open or closed until the final 5-element outcome where it must be open across multi-vendor interfaces to realize the vision of Open RAN.

As a closed RAN progresses towards a fully integrated Open RAN architecture, the path can add each of the following elements:

Virtualization:

- This transition path involves the shift to a virtualized environment.
- Initially, the focus is on virtualizing software functions, enabling them to run on general-purpose hardware. This step prepares the network for further openness and flexibility.

Disaggregation:

- This path emphasizes the separation of hardware and software components.
- COTS hardware is introduced, allowing software functions to run on more flexible and open platforms. Disaggregation paves the way for future scalability and customization.

Open Interface:

- Open interfaces facilitate interoperability between different vendor components, enabling seamless integration. This step enhances the network's flexibility and promotes innovation.

Cloud Native:

- This path involves transitioning to a cloud-native architecture.
- Disaggregated components are combined with cloud-native principles, making use of containerization and microservices. This step optimizes resource utilization and scalability, setting the stage for more advanced capabilities.

Three distinct transition paths are proposed below:

1. **Hardware First:** The first transition path, as shown in Figure 17, starts with a virtualized RAN and follows a direction that adds disaggregation, then open interfaces and finally cloudification to the RAN architecture. This is called 'Hardware First' since it follows the path of building virtualized, disaggregated RAN components on the same bare metal servers as it transitions to disaggregation and open interfaces before changing hardware to a cloud native platform.

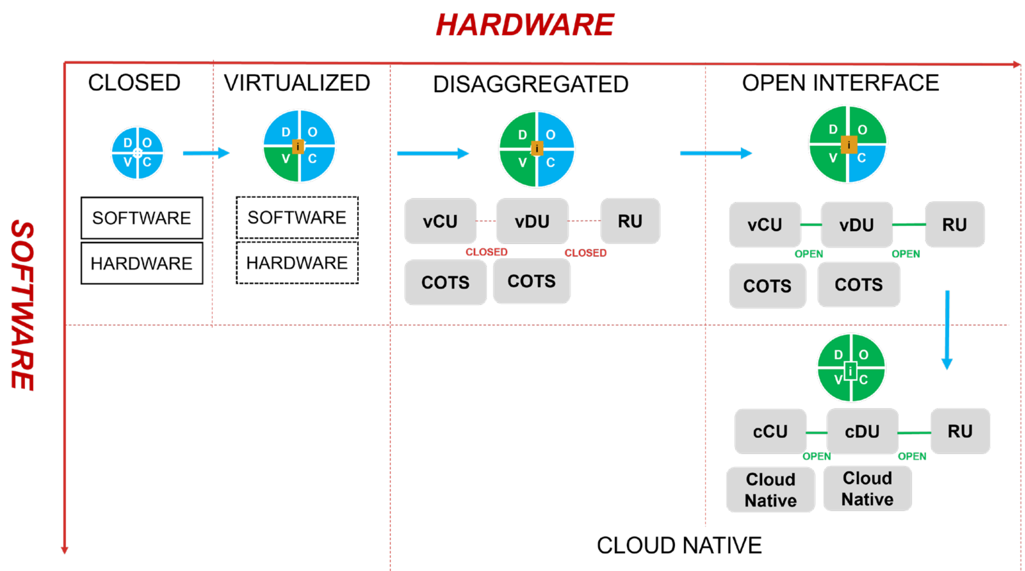

Figure 17. Hardware First transition path to Open RAN

2. **Software First:** The second transition path, shown in Figure 18, starts with a virtualized RAN and follows a direction that adds disaggregation, then cloud native, and then open interfaces to the RAN architecture. This is called 'Software First' since it follows the path of building virtualized, disaggregated components on bare metal servers and transitions to a cloud native platform and then transitions to an open interface.

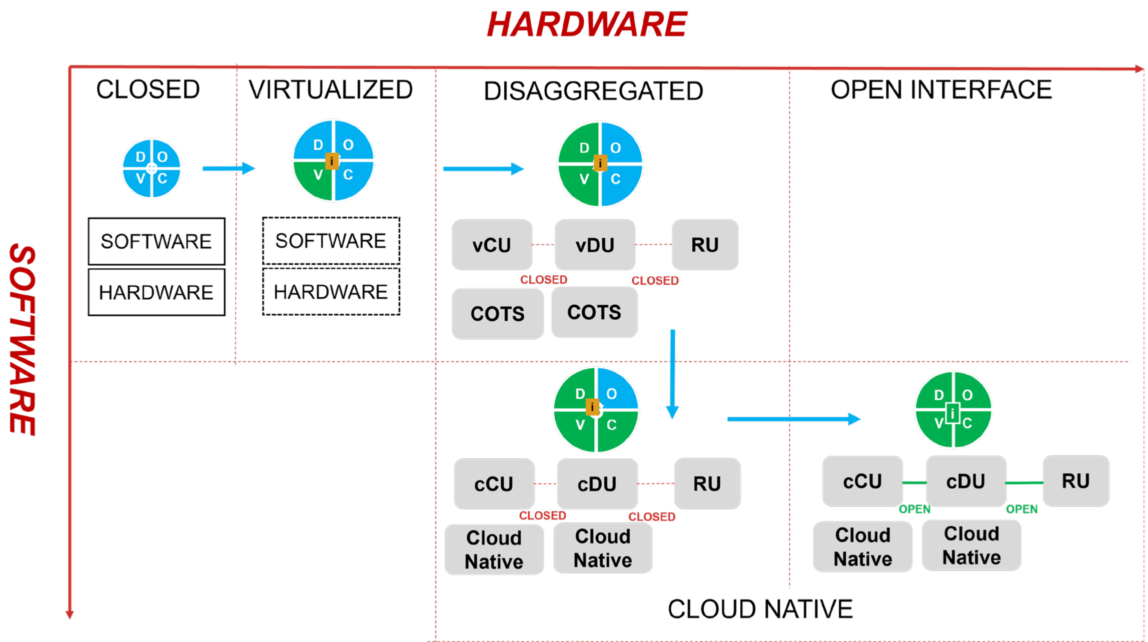

Figure 18. Software First transition path to Open RAN

3. **Direct Path:** The third transition path, shown in Figure 19, starts with a virtualized RAN and follows a direction that adds disaggregation on bare metal servers, then transitions directly to open interfaces and cloud native RAN architecture. This is called 'Direct Path' since it follows the path of building virtualized, disaggregated components on bare metal servers and then transitions directly to an open interface, cloud native platform.

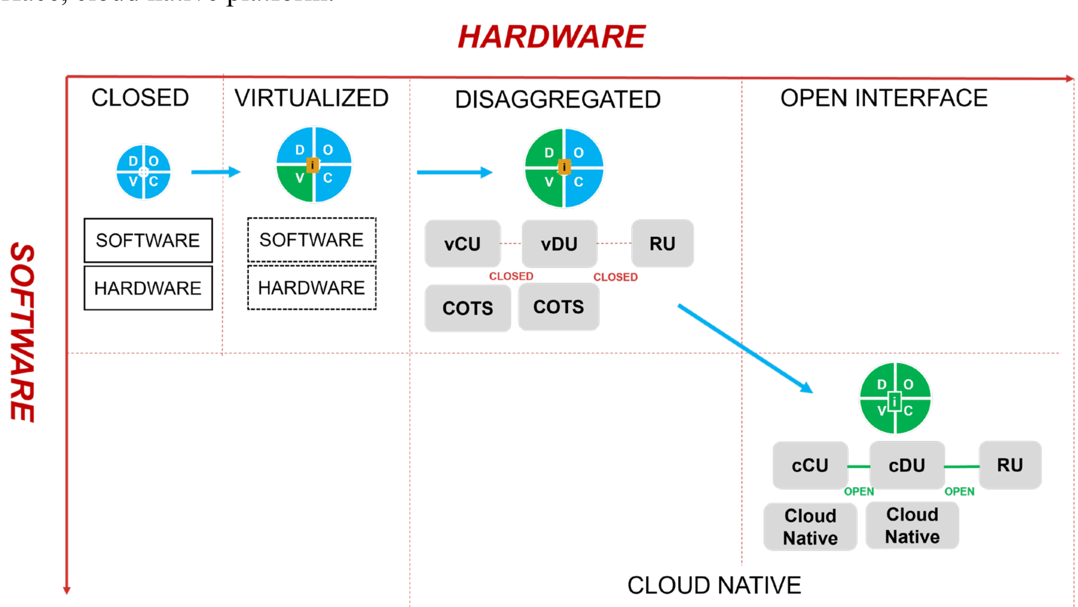

Figure 19. Direct transition path to Open RAN

Each transition path offers a strategic sequence of steps to guide the migration from a closed vRAN deployment towards a more open and adaptable Open RAN network architecture. The MNO RAN transition journey is at its own pace and selected path based on business goals, network needs, and network deployment strategy. The overall transition approach is intended to provide paths that make sense to an MNO and offer various levels of integration that can be temporary or permanent.

7. Conclusion

The Open RAN ecosystem continues to evolve towards the vision of RAN components as a virtual software application capable of working on any bare metal hardware operated with orchestration and automation. A fully featured Open RAN architecture complements 3GPP 5G RAN specifications and incorporates five key elements into RAN architecture, namely, disaggregation, virtualization, open interface, intelligence, and cloudification. Key benefits include a shift away from monolithic infrastructure and a move towards multi-vendor, plug-and-play interoperable components that offer flexibility, vendor diversity, and innovative freedom.

The Open RAN ecosystem is vibrant with a broad range of industry activity that includes commercial mobile network operator deployments, industry testbeds and trials, and government policies and investment. These activities demonstrate proof-of-concept and end-to-end validation of Open RAN subsystems and systems. Several mobile network operators across the globe have deployed greenfield and brownfield commercial Open RAN networks while others have made public announcements of field trials, partnerships, and commitments to Open RAN deployments.

Governments such as the United Kingdom, United States, Australia, Germany, Canada, Japan, South Korea, and Singapore are investing in and promoting the development, adoption, and deployment of Open RAN.

CableLabs/Kyrio is a recognized industry leader in the Open RAN ecosystem as a system Integrator, independent and neutral host of a fully featured Open RAN test lab, Open RAN subsystem and system test experts, and contributors to SDOs. Test results, observations and lessons learned from these Open RAN test activities demonstrate progress towards Open RAN adoption proving multi-vendor e2e interoperability with multiple vendors.

A proposed Open RAN transition approach offers three transition paths to achieve the outcome of fully integrated Open RAN architecture, namely, Hardware First, Software First, and Direct Path. Each transition path offers a strategic sequence of steps to guide the migration from a closed vRAN deployment towards a more open and adaptable Open RAN network architecture. The choices among these paths depend on the network operator's goals, existing infrastructure, and desired outcomes. The overall transition approach is intended to provide paths that make sense to an MNO and offer various levels of integration that can be temporary or permanent.

Future study includes methods to develop operator deployments of multi-vendor e2e interoperability solutions based on common deployment profiles, common industry test plans, and further detailed total cost of ownership analysis. The future of wireless networks starts with Open RAN. The potential for secure and reliable networks built on multi-vendor components that are easy to upgrade to future generations of network technologies is recognized by many governments, mobile network operators, vendors, and labs. Working together, the ecosystem can bring this potential to fruition in the near future.

Abbreviations

3GPP	3rd Generation Partnership Project
RAN	Radio Access Network
CU	Centralized Unit
DU	Distributed Unit
RU	Radio Unit
eMBB	Enhanced Mobile Broadband
gNB	gNodeB
URLLC	Ultra-reliable Low Latency Communications
mMTC	Massive Machine Type Communications
CPRI	Common Public Radio Interface
SCTE	Society of Cable Telecommunications Engineers
vRAN	Virtualized RAN
SDO	Standards Development Organizations
TIP	Telecom Infra Project
IMDA	Infocomm Media Development Authority
5G	Fifth-generation technology standard for broadband cellular networks
US	United States
UK	United Kingdom
NFV	Network Function Virtualization
MANO	Management and Orchestration
COTS	commercial-off-the-shelf
SMO	Service Management and Orchestration
PNF	Physical Network Functions
MOCN	Multi-Operator Core Networks
MORAN	Multi-Operator RAN
RIC	RAN Intelligent Controller
e2e	end-to-end
DCMS	Department of Culture Media Sport
NTIA/ITS	National Telecommunications and Information Administration's Institute for Telecommunication Sciences
CBRS	Citizens Broadband Radio Service
SAS	Spectrum Access System
UE	User Equipment
RF	Radio Frequency
WG	Work Group
TIFG	Test and Integration Focus Work Group

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