altice labs

# 5G radio units towards virtualized RAN

Open RAN; Function disaggregation; Interface standardization; Open interfaces; 5Growth

## White paper

**Version 1.0, June 2021**

# Introduction

The next decade is expected to be profoundly impacted by 5G. By the end of 2020, more than one-fifth of the world's countries will have launched 5G services – particularly, in Europe, the expected 5G penetration should reach 30% by 2025 [1]. Mobile communications are foreseen as the enablers for a new industrial revolution. Thus, as the global pacesetter for convergence of all connected technologies bringing this technology transformation to fruition economically and efficiently.

It has become clear that 5G technology deployment must use a combination of the low and high-frequency spectrum, requiring a much higher degree of cell densification (primarily achieved via small cells and distributed antenna systems deployment) to guarantee the desired quality of service (QoS).

Furthermore, the COVID-19 pandemic brought numerous challenges and uncertainties to the telecom industry, including geopolitical stress escalation and additional 5G deployment challenges. This pandemic leads to an unprecedented disruption, transitioning millions of workers to home-based offices and students to online classrooms while increasing the demand for video, collaboration, and entertainment services. Furthermore, trade war, exacerbated by COVID-19, is restricting the number of vendors available to deploy 5G and creating additional pressure and uncertainty in operators, increasing the lock-in feeling and hindering innovation.

To better deal with these challenges, an open radio ecosystem is required in order to promote transition between proprietary "end-to-end" solutions to an open market of "best-of-breed" system designs offered by numerous vendors, and giving flexibility in network deployment, upgrade, and swap. This would allow to reduce solution cost and contribute, for example, to provide broadband access in remote zones, otherwise non-existent, while providing social inclusion, well-being, and technological integration, particularly important in confinement times.

With such challenges in mind, the design evolution from LTE to 5G new radio (NR), where the original baseband unit (BBU) functions are distributed between three different elements – a centralized unit (CU), a distributed unit (DU), and a radio unit (RU) – will enable the adoption of the necessary technological enablers such as open and standardized interfaces, network functions virtualization and software-based implementations. This approach will facilitate the cloudification of radio access networks (cRAN), allowing resource centralization while better promoting radio access networks virtualization (vRAN), enabling the use of commercial off-the-shelf (COTS) hardware, and also pave the way for decreased fronthaul line rates while meeting latency demands.

# Concept of open RAN

The radio access network (RAN), as defined by 3GPP, is already open when it comes to the air interface and the interfaces toward the core network, which are well standardized, enabling devices and nodes from different vendors to interoperate. However, RAN within itself is closed, and markets today are dominated by a small number of incumbent vendors. In a bid to generate more competition and increased vendor diversity, some mobile network operators (MNO) support the concept of an open RAN, to create a more competitive market with more rapid innovation cycles in which proprietary RAN technologies are replaced by open standard alternatives, and disaggregating the base station architecture and its functional components.

Open RAN can be understood as “***the ability to integrate, deploy, and operate RANs using components, subsystems, and software sourced from multiple suppliers, connected over open interfaces***” [2]. O-RAN Alliance refers that “***future RANs will be built on a foundation of standardized interfaces, virtualized network elements, white-box hardware that fully embrace the core principles of intelligence and openness***” [3]. In the next sections, these three key initiatives will be better explored and explained.

# Standardized interfaces

This section will review in detail the role of interface standardization for the various 5G RAN dimensions.

## 5G-NR logical architecture and functional splits for midhaul/fronthaul

The 5G RAN will evolve from the traditional BBU and remote radio head (RRH) architecture used in 4G networks to a DU, CU, and RU architecture, which will better facilitate RAN virtualization and flexible assignment of computing resources across network entities, depending on the MNO network deployment strategy.

**Figure 1** presents the architecture evolution from 4G to 5G [4].

The BBU is disaggregated by moving some of its functions to the RU (Low PHY), DU, and CU. Part of the user plane (UP) functions are also moved from the evolved packet core (EPC) to the CU. The two new transport links between CU and DU and between DU and RU are frequently called fronthaul-II (or midhaul) and fronthaul-I (or simply fronthaul), respectively. The specific functions deployed in CU, DU, and RU are well defined. However, the way these entities are deployed on the network is flexible and allows distinct strategies, as we will see in the next sections.

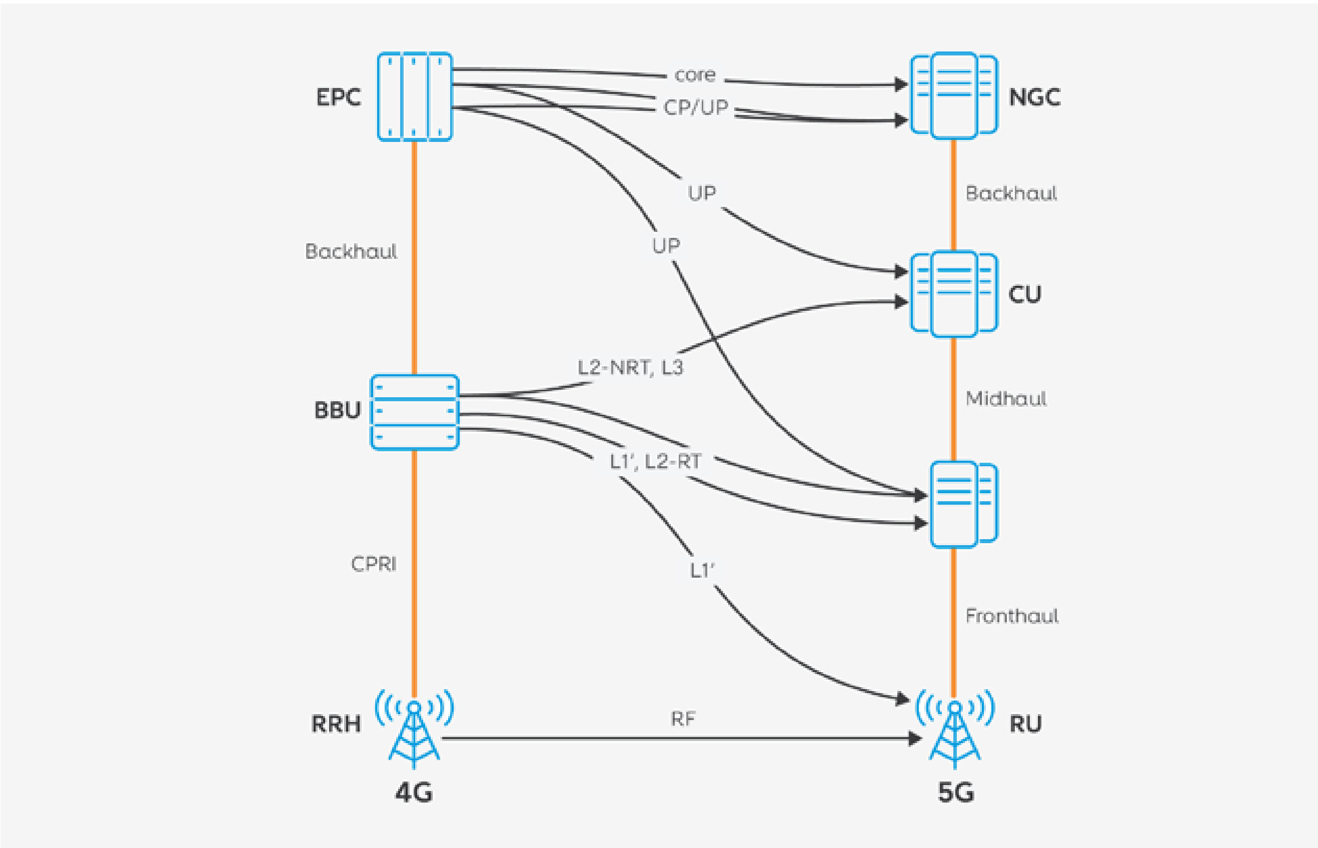


**Figure 1 –** Evolving from monolithic BBU in 4G to split function architecture in 5G [4]

To disaggregate the BBU functions, 3GPP defined eight functional split options for midhaul (CU-DU) and fronthaul (DU-RU) and selected the packet data convergence protocol (PDCP) / high radio link control (RLC) - option 2 - as the high layer split point, staying open for any low layer split, respectively. Other standardization bodies, namely Small Cell Forum (SCF), O-RAN Alliance, and the Common Public Radio Interface (CPRI) cooperation, have also made some efforts to identify different split points. **Figure 2** maps the different splitting points from these different groups.

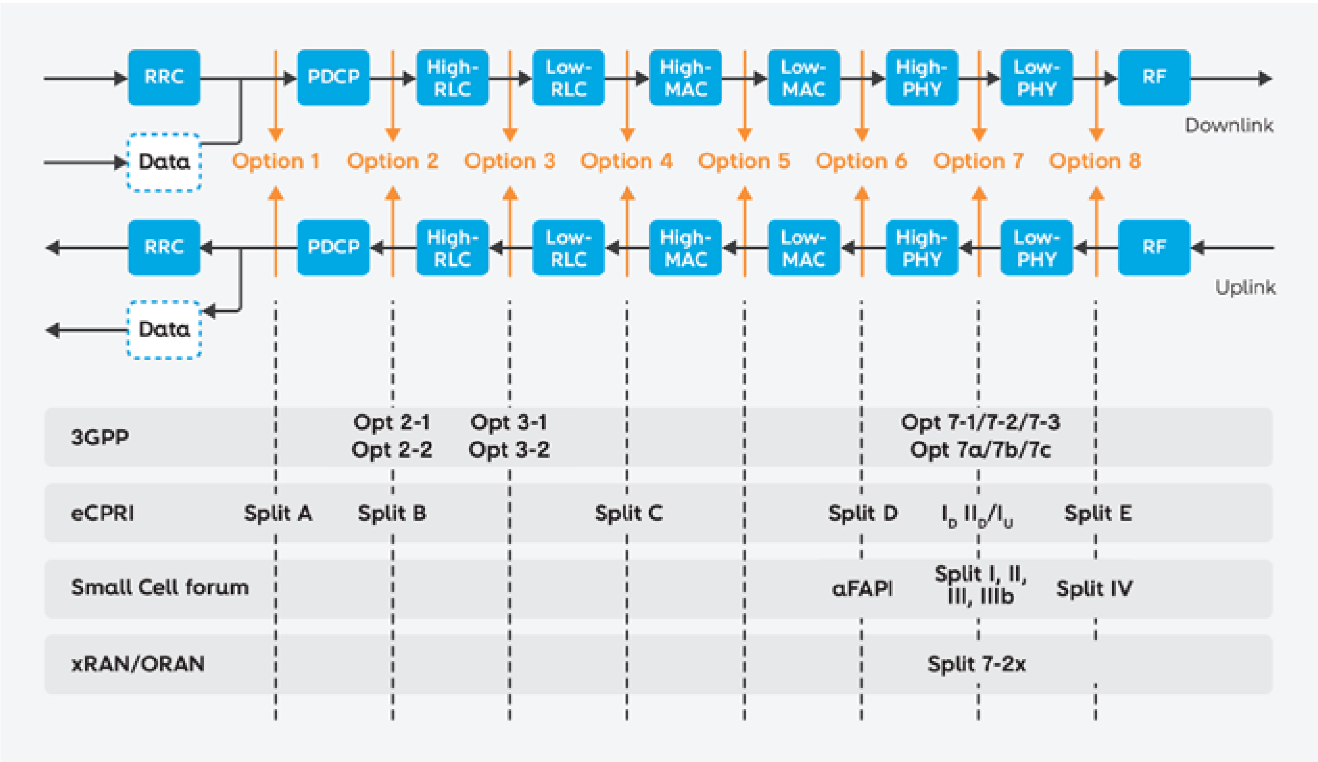


**Figure 2 –** Mapping different split points to the 3GPP model in 3GPP, CPRI cooperation, SCF, and O-RAN [5]

Basically, the optimal splitting point is a trade-off between coordination gain from functional centralization and latency and bandwidth requirements in the transport network, as shown in **Figure 3**. Centralized RAN considering lower layer splits (LLS) requires high transport capabilities (with both high bandwidth and low latency) and, in conventional fronthaul (option 8), continuous bitrate transport for very high transport applications. However, it allows the centralization of all high layer processing functions and coordination gain. On the opposite side, a distributed RAN architecture considering backhaul or higher layer splitting (HLS) options makes the transport requirements soft but implies higher site cost and complexity and limited coordination between cells.

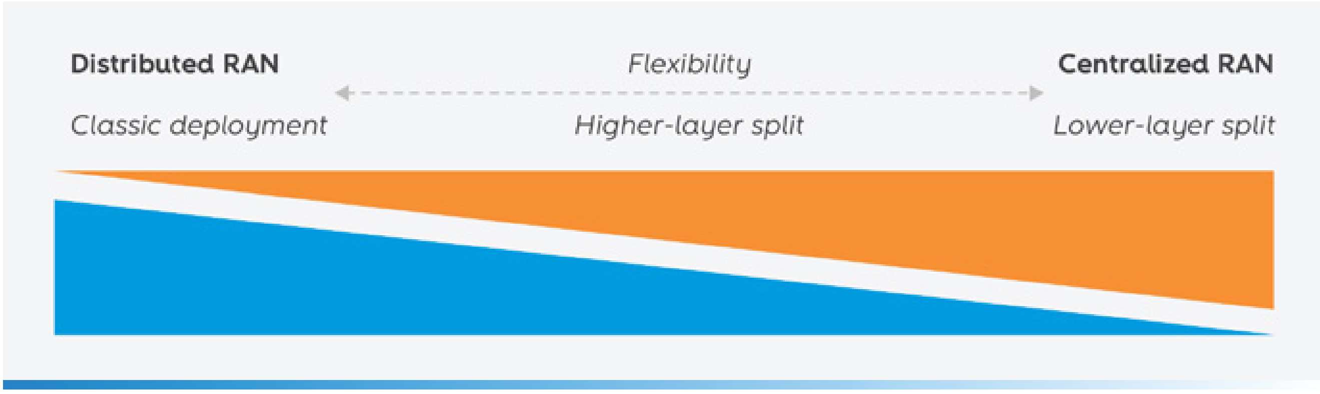


**Figure 3 –** Centralized vs. distributed RAN [6]

The choice between HLS and LLS is not always easy and aims to find the optimal economic and performance balance point for each MNO. Moreover, it may make sense to use different models for different regions (rural vs. urban) or different use cases. For example, HLS is more desirable for capacity use cases in dense urban areas, while LLS will be the optimum solution for coverage use cases. Cascaded-split architecture is also considered to allow additional flexibility.

## Open interfaces – standards

The open RAN concept assumes full interoperability between RAN elements from different vendors. An MNO can deploy a fully compliant functional split architecture, but unless the interfaces between RU, DU, and CU are open, the RAN itself will not be open [7]. In this way, standardization constitutes a mandatory feature.

Currently, only split option 2 presents a standardized interface (the F1 interface), the primary new interface for midhaul, and was already specified by 3GPP with TS 38.470 to TS 38.475. It supports control and user plane separation (F1-C and F1-U) and separates radio and transport network layers.

Beyond the commonly accepted split 2, splits 6 and 7 are the ones the industry has, so far, highlighted for fronthaul. In fact, the option 7 split point has been further diversified by several groups. One of the earliest standards and the most accepted is O-RAN open fronthaul interface specified by O-RAN Alliance WG4 that considers split 7-2x. This open standard details all of the signaling formats and control messages needed for multi-vendor DU and RU equipment to interoperate. It supports both enhanced CPRI (eCPRI) and radio over Ethernet (RoE) transport mechanisms and separates control, user, synchronization, and management planes (CP, UP, SP, and MP). The standard has been in development since 2017, and the latest version of this specification, Release 3, is now available on the O-RAN Alliance website [8]. There are already available some commercial deployments using the O-RAN fronthaul specification.

On the other hand, SCF has defined the network functional application platform interface (nFAPI) to use with split 6. This interface is an evolution of FAPI, an internal interface within an integrated or disaggregated small cell, and started its release in July 2019 [9]. However, SCF225, the network FAPI for the physical layer (PHY) and medium access control (MAC) split specification, is still under development.

Note that not only the midhaul/fronthaul interfaces are relevant for an open RAN architecture, but also the 3GPP standardized interfaces must be really open. One example is the optional X2 interface in legacy 4G that, even though being standardized by 3GPP, many incumbent vendors intentionally did not implement or used many proprietary messages. However, to guarantee a seamless function in a multi-vendor environment, this interface becomes essential. It is even more relevant in 5G non-stand alone (NSA) deployments and is forcing MNO to deploy 5G using their existing 4G vendors [10].

## Transport options for midhaul and fronthaul

5G deployment foresees a massive number of cell sites. To achieve this, the MNO need to rely, as much as possible, on the currently installed network infrastructure. Passive optical network (PON) technologies and architecture present a good trade-off between network coverage, ease of integration, available resources, and fitness for the considered network scenarios. The PON networks present as a strong candidate to allow the massive deployment of 5G cells, both due to the evolution of the PON technologies that will tend to support bandwidths of 50 Gbps and above, and its extensive geographical coverage and termination points density. The PON allow different transport options and strategies, depending on the specific requirements of implementation. **Figure 4** depicts how the PON covers those different transport options.

There are advantages and disadvantages to any of these approaches, and all these options may be adopted in different situations.

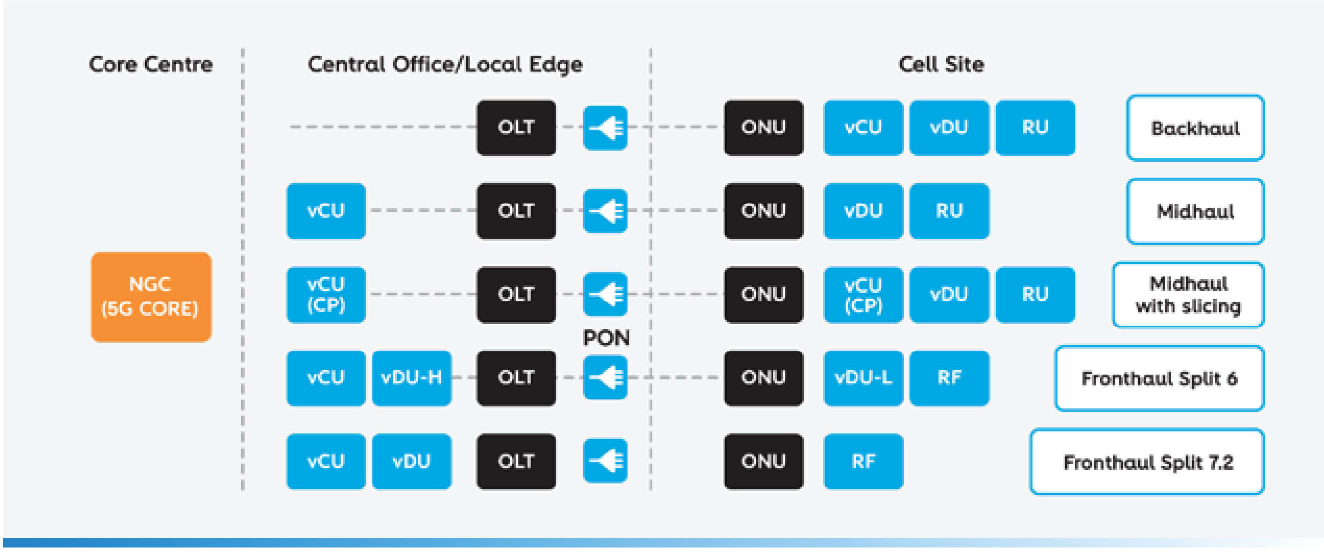


**Figure 4** – Open RAN deployment scenarios considering PON as the transport network

# Cloudification and virtualized RAN

One consequence of the previously described functionality desegregation is the ability to, once decoupled, place these different functions in separate physical locations, allowing for simpler and less expensive hardware implementations (for example, in remote locations with more stringent requirements in terms of power and/or space constraints). Furthermore, this process can be optimized by distributing the more typically centralized elements across multiple cloud environments (e.g., edge cloud, large datacentres, etc.) [11].

In essence, network cloudification allows for the extension of cloud platform technologies and their virtualization capabilities throughout a communication network, resulting in the increment of flexibility, agility, and scalability that the new 5G telecommunication network deployments require.

Cloud technologies, which fundamentally changed the way we look at computations, and more importantly, the pace of innovation, build upon a combination of principles:

### Disaggregation

Breaking vertically integrated systems into independent components with open interfaces.

### Virtualization

Being able to migrate components from custom-built nodes and run multiple independent copies of those components on a common (generic) hardware platform.

### Commoditization

Being able to elastically scale those virtual components across commodity hardware bricks as workload dictates [11].

With the advent of open RAN for 5G, which advocates for open, interoperable interfaces and hardware-software disaggregation, the implementation of such cloud technologies becomes a major technological enabler for 5G networks.

Cloud technology presents innovative alternatives for such RAN deployments, complementing the existing and proven purpose-built solutions by implementing RAN functions over a generic compute platform and by managing RAN application virtualization using cloud-native principles. This way, selected 5G RAN functions (e.g., CP and UP functions in the CU or latency-sensitive radio processing functions in the DU) can be implemented through COTS hardware platforms [12] [13].

This process can be extended and replicated by distributing the more centralized elements across various clouds, including large datacentres that already benefit from elasticity and economies of scale, as depicted in **Figure 5**.

Of particular importance is the concept of network function virtualization, allowing dynamic scaling (in and/or out) of functions according to the demand (capacity, throughput, and load balancing).

Currently, MNO are looking into virtualized RAN solutions also as an enabler to reduce the total cost of ownership (TCO) [14].

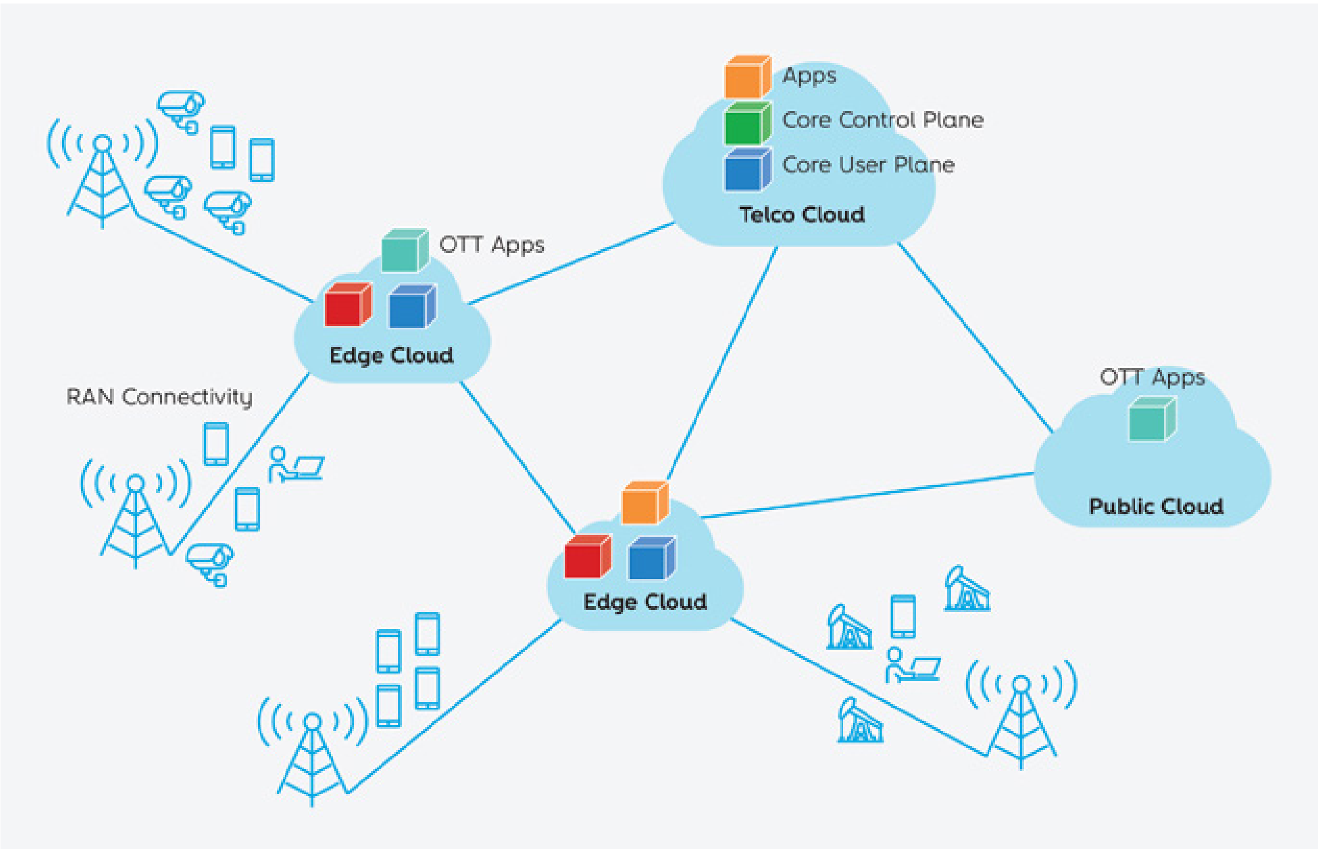


**Figure 5 –** Multi-tenant / multi-cloud (including virtualized RAN resources and conventional compute, storage, and network resources) hosting both TELCO and OTT services and applications

# White box hardware architecture

In parallel to the trend of using COTS hardware to provide the higher layer functions (as presented before), the MNO and industry alliances are also looking into open hardware for the lower layer functions, based on the white box concept.

The O-RAN White Box Hardware Working Group (WG7) released two specifications focused on the utilization of open hardware architectures for the implementation of 5G base stations, namely, the "Deployment Scenarios and Base Station Classes for White Box Hardware" and the "Indoor Picocell Hardware Architecture and Requirement (FR1 Only) Specification". The second document presents the architectural diagrams, the functional module descriptions, and the interfaces for the CU, DU, RU, and fronthaul gateway (FHGW) modules, considering the functional splits 8, 7-2, 6, and 2. It defines the performance, interfaces, environmental, electromagnetic compatibility, mechanical, thermal, and power requirements for all the supported splits.

**Figure 6** presents the functional modules of an open RU (O-RU) accordingly to the functional splits 8, 7-2, and 6, as well as a DU+RU monolithic box in case of split 2. The radio frequency (RF) processing unit remains the same independently of the functional split adopted. On the other hand, most of the operations performed by the digital processing unit depend on the considered split. The figure shows both the common and the specific operations depending on this design/deployment decision. Regardless of that, the digital processing unit can be efficiently implemented on a digital programmable device, such as an FPGA or a multiprocessor programmable system-on-a-chip (SoC), containing both reconfigurable logic and hardwired multicore processors. That means the same device and implementation platform can be used for distinct deployment scenarios. Multicore hardwired processors are particularly adequate for implementing the RLC and MAC layers, while the programmable logic of the multiprocessor SoC (MPSoC) is used for the remaining digital processing unit operations that are more processing-intensive and/or require timing accuracies at the clock cycle level.

Moreover, since the physical interfaces, both network and RF, are the same, regardless of the splitting options, it is feasible the dynamic modification of the deployed split as well as the installation of field upgrades.

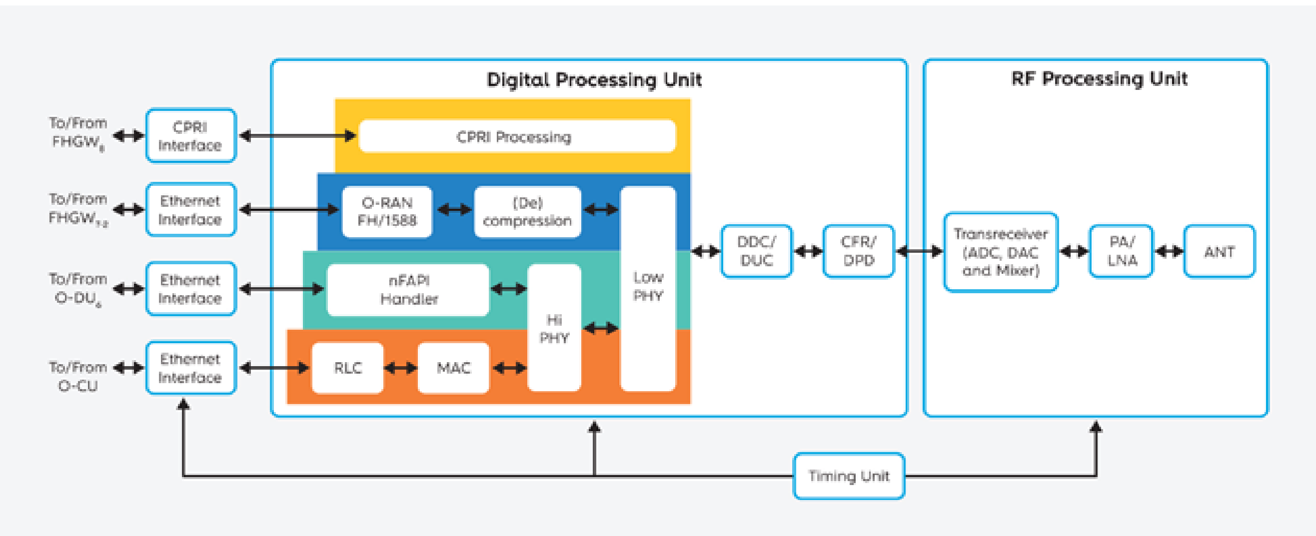


**Figure 6 –** Functional modules of an O-RU accordingly to the functional splits 8, 7-2, and 6, and a monolithic gNB DU+RU in case of split 2

# Requirements and drivers for open RAN

There are several businesses and technical drivers to embrace an open RAN architecture. Managing CAPEX and OPEX in the RAN is critical as continuous growth in data traffic can drive the TCO of mobile access networks up by three times [15]. CAPEX and OPEX need to be kept at a lower level because of the need for network densification and for cases where economies of scale are not applicable, such as in rural or enterprise vertical deployments, requiring much lower cost solutions to stimulate further deployments. From a technical point of view, centralization and virtualization are an operator's old desire because of scalability limitations of traditional architectures and the constraints of incumbent vendors lock-in. They are also seeking for 5G new business models and use cases consolidation.

## OPEX and CAPEX reduction

Standardized interfaces and software/hardware disaggregation allow opening the infrastructure market to more flexible and agile companies, which will enable reducing the network cost in the medium/long term. Software and hardware disaggregation allow scalable, cost-effective, and fast network deployments, upgrades, and swaps, if that hardware and software components are interoperable and can be mixed and matched from different vendors. Network architectures where CU and DU functions tend to be at central locations and away from location-constrained cell sites will allow MNO to benefit from reduced cell site hardware footprint and resources pooling gains. RU and DU separation also allow lower-cost radios for network densification as less intelligent RU will cost less. Open RAN implementations will potentially also allow MNO to significantly reduce OPEX through remote operations and maintenance [16].

## Technical drivers

Splitting up the next generation node B (gNB) between CU, DU, and RU, and virtualizing them will bring the necessary flexibility to the network. The gNB can be scaled flexibly from a small (single DU) to a large size (accommodating multiple DU), agnostic of DU hardware types for various deployment environments. The CP and UP may also be dimensioned and scaled independently. CU-UP can be sliced into multiple CU-UP and can be deployed in independent locations (as shown in **Figure 4**). This separation also enables adaptation to various use cases and the QoS that needs to be supported (i.e., gaming, virtual/augmented reality, etc.) [7].

Aggregating CU and/or DU at centralized locations allows coordination between different RU (co-located or not) for performance features, like coordinated multi-point (CoMP), load management, real-time performance optimization, and more reliable mobility.

Increasing the supply chain diversity (i.e., having more vendors), in addition to cost reduction, will also promote innovation. New vendors need to create new markets, innovation, and service markets that large incumbent vendors either have no interest in or cannot provide solutions for. For example, deploying private cellular networks for small-to-medium enterprises (SME) is not a market where tier-one vendors are interested due to specific requirements and smaller individual contracts. This is where new and smaller vendors could excel and create innovative solutions [16].

# Key challenges

The success of open RAN will be, essentially, dependant on the following three key challenges.

**Interoperability and integration –** A truly fully interoperable solution must be achieved to allow multi-vendor deployment scenarios and avoid vendor lock-in. Some initiatives are taking place to facilitate integration and interoperability validation. The Open Test and Integration Center (OTIC) initiative was launched to verify, integrate, and test components functional compatibility to O-RAN specification[17] [18]. The goal is to develop an ecosystem with many different solutions, assured to work together, from which system integrators can select to build solution portfolios. Standard entities as O-RAN Alliance are also specifying interoperability tests for the new open interfaces [19] [20].

**Operational complexity –** Traditionally, MNO rely on a single vendor to resolve issues and problems. A multi-vendor environment brings additional challenges, as it might not be immediately clear the cause of a specific problem and the product/vendor responsible for it, imposing higher operational risks [21]. For example, it can be difficult to establish with precision where bottlenecks are located when experiencing delays. To mitigate this, a service level agreement (SLA) with each vendor should be defined, just like the multi-vendor traditional approach (e.g., between EPC and RAN).

**RU market under-development –** The RU market supporting the open fronthaul 7.2x from O-RAN Alliance is still under development. Additionally, as referred to previously, there are still open interface specifications under development. If these open solutions take too long to get mature, there is a high risk that the traditional, vendor-specific solutions are adopted due to the operators' urgency to deploy 5G quickly.

# Use cases and business opportunities

When considering dense built-up areas where propagation through obstacles, such as buildings and trees, can be an issue, operators need to densify their mobile networks with small cells for 5G coverage and QoS enhancement. Such use cases of coverage extension and densification are considered the main scenarios for open RAN network deployment with non-incumbent vendors [22].

There are several attributes of the 5G-era use cases and 5G-era technologies that make small cells ideal candidates for the roll-out of 5G, as shown in **Figure 7.** For example, the massive density of the 5G-era internet of things (IoT) use cases suggests using small cells, as they can be deployed in high-density areas due to their small physical form factors. Additionally, small cells bring several deployment benefits, as it has already been demonstrated in the 3G & 4G eras.

Next, we present some relevant practical use cases where the 5G deployment approach mentioned above can play a relevant role.

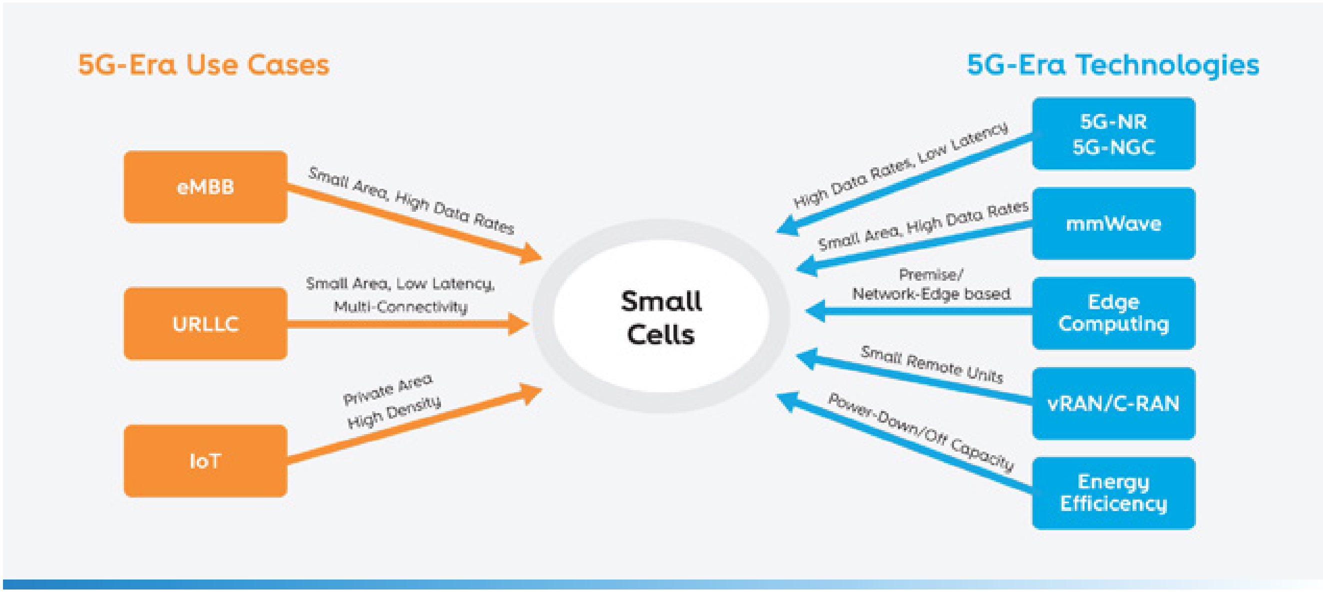


**Figure 7 –** Rationale for 5G small cells [23]

## Outdoor hotspots

MNO will look at small cell technology in order to add data capacity in areas of traffic congestion. A dense, small cell network increases both the radios per subscriber and provides subscribers improved signal quality for more efficient data transfer. The shorter distance between radio sites also helps overcome the higher frequency 5G radio spectrum's short signal reach. As a result, small cells are becoming the leading solution in growing the network's data capacity.

In addition to the possibility for an easier and less costly 5G network densification, 5G small cells also allow increased network flexibility and reduced network expansion complexity.

## Neutral host providers

Neutral host providers (NHP), a third-party non-operator entity, will arise specifically to deploy 5G small cells in urban centers, historical downtowns, or public buildings. In many of these cases, there is no business case for large MNO to invest in their own network densification or, there are local entities or regulatory constraints. This is an opportunity for NHP to deploy a network to be rented to different MNO and potentially reduce operators' OPEX and CAPEX (shown in **Figure 8**).

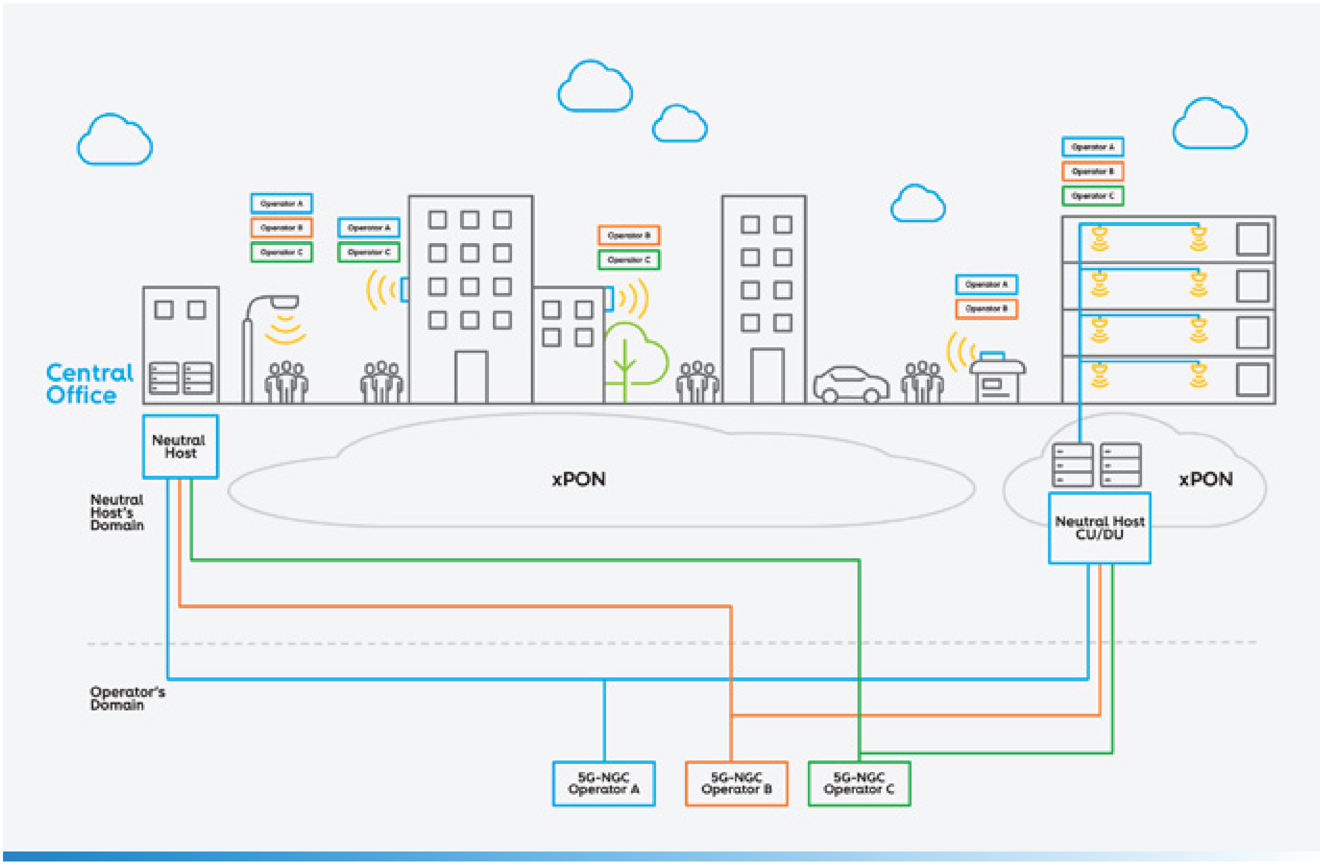


**Figure 8 –** Neutral host networks use case

## Private networks

Many large enterprises, businesses, and public entities, who want to control security or guarantee it, are exploring private 5G networks, independent end-to-end small/medium-sized 5G networks, recurring to the 5G small cells and open RAN architecture (depicted in **Figure 9**). This may be of interest, particularly in the contexts shown next.

Industrial centers that require critical communications, i.e., needing availability, reliability, QoS, and security.

Large companies and facility owners that require secure networks, high throughput, and QoS.

5G

Municipalities that aim to deploy smart cities solutions.


**Figure 9 –** Private networks use case

## Other use cases

Other use cases for 5G small cells implementation using open RAN architecture are:

Indoor small cells solution to solve coverage/capacity problems for medium/large businesses and facility owners. RU may work as an indoor distributed antenna system (iDAS).

Rural small cells for coverage in extensive areas of low population density. This allows MNO to comply with the population coverage objectives at a reduced cost and provide broadband access in remote zones, otherwise non-existent, while providing social well-being.

# 5G open RAN @ Altice Labs

There are two main open RAN R&D paths at Altice Labs that complement each other. The first one aims to test and optimize midhaul and fronthaul transport (in an O-RAN architecture) over the PON. The second one intends to design and implement a RU prototype also incorporating the optical network unit (ONU) (e.g., XGS-PON) functions. To achieve the proposed goals, and taking into consideration that (i) a complete C-RAN is needed for integration and test; and (ii) it is very complex and out of our current scope to develop the DU and CU entities, Altice Labs has decided to survey the market and select a 3rd party solution for the missing components. As a result, an evaluation kit (EVK) from ASOCS [24] was acquired. This evaluation kit is a completely functional 5G C-RAN (as present in **Figure 10**), and it is being used to support the ongoing R&D activities.

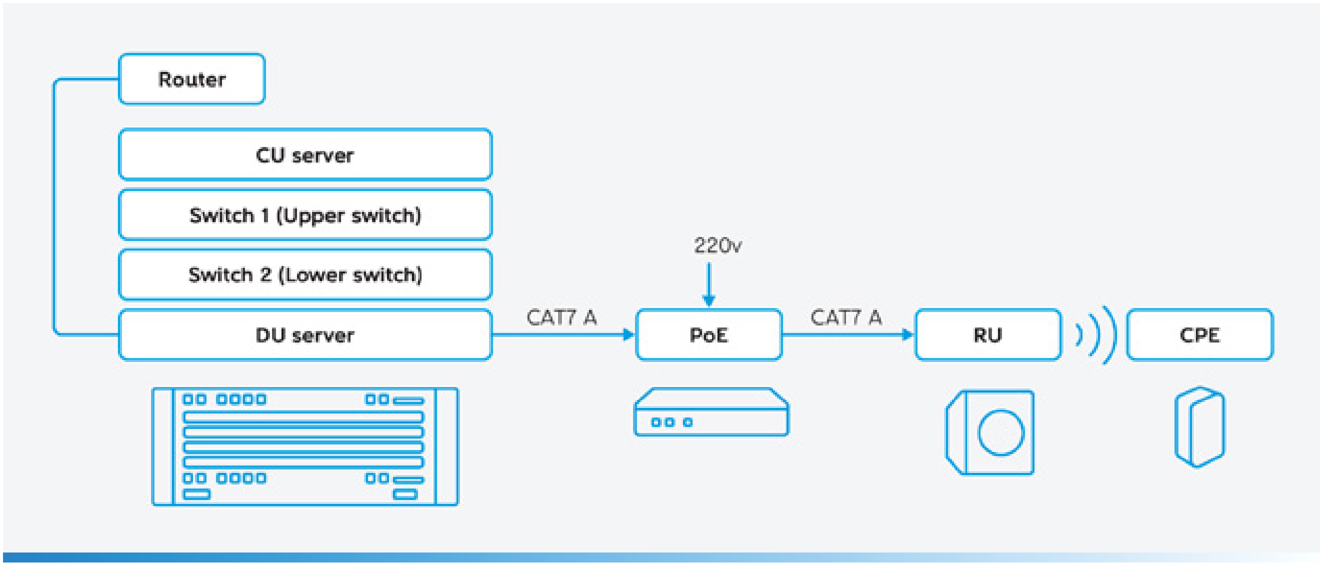


**Figure 10 –** ASOCS open RAN evaluation kit

This kit provides end-to-end cellular connectivity for 5G NR - stand alone (SA) from the new generation core (NGC) to the end device. The system is virtualized by software that runs on COTS servers and interfaces with RU using ethernet fronthaul, which is compliant with the ORAN-FH (split 7.2, Fronthaul) interface. The CU-DU interface is 3GPP compatible and implements split 2 (midhaul). The CU server runs the CU application, and the NGC/5G core (5GC) application can be externalized from third-party Metaswitch [25]. It also runs the license manager and management system.

## PON integration for midhaul and fronthaul transport

The ongoing research aims to evaluate the constraints of using PON technologies both on the fronthaul (DU-RU connection) and on the midhaul (CU-DU). We are using an OLT and an optical network unit (ONU) with XGS-PON – 10G/10G.

We need to evaluate the impact of PON latency, jitter, and particularly the asymmetry between downstream and upstream. Maximum fiber distance and bandwidth consumption are also important aspects to be evaluated. The need to have G.1588 precision time protocol (PTP), a phase and time synchronization protocol, on the PON (OLT and ONU) will be evaluated to both transport options under different network conditions.

## RU prototype design and implementation

As referred, an immediate main challenge for open RAN is the RU availability. Altice Labs, in collaboration with Instituto de Telecomunicações de Aveiro (IT Aveiro), is prototyping an RU that will be used, in integration with the ASOCS EVK, to support many of the ongoing 5G R&D activities at Altice Labs. The main goal is to achieve a prototype that combines the RU functions with the ONU functions in a compact design. The final goal is that these research activities lead to an open RAN RU product or product line. **Figure 11** shows this RU prototype.

As stated before, the RU prototype under development will be used to support demonstration scenarios from multiple ongoing research projects. One of them will be a 5G small cell scenario for railway coverage, monitoring, and control in Aveiro seaport, under the H2020 5Growth European Project framework. This project addresses both enhanced mobile broadband (eMBB) and ultra-reliable and low-latency (URLL) use-cases. In the first one, HD video 16Mbps should be transmitted from a camera installed in the railroad crossing to the moving train. In the second case, railroad crossings should be controlled by sensors installed in the train line. Both use cases will be using a 5G cell. On top of it, a distributed, low footprint solution is required due to the lack of space and installation restrictions.

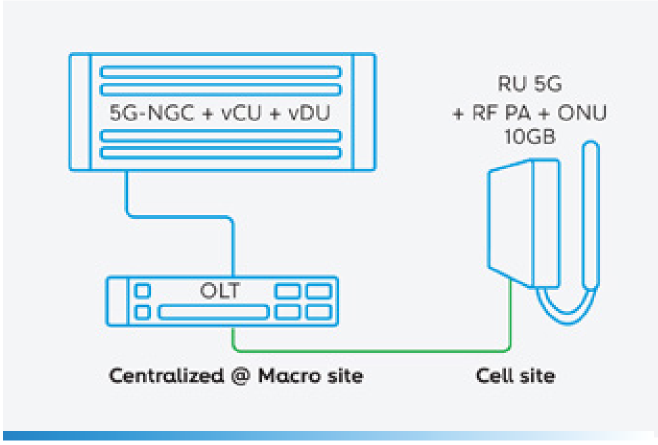


**Figure 11 –** RU prototype for European R&D projects

In the scope of this, some key challenges are being addressed. One challenge is the RF power amplifiers' market availability, working in the new 5G n78 frequency band (TDD 3.5GHz). Another challenge is the existence of some incompatibilities between O-RAN products that requires some adaptions.

# Conclusions

There is growing enthusiasm for open RAN with some products already available on the market and some ongoing deployments. Standardization is moving forward, but in some cases, it is not yet completed.

Of the main players, MNOs are the most interested in open RAN for the promise of cost reduction that may enable the 5G business case, greater flexibility, a decrease of lock-in situations related to legacy vendors, and enhancing innovation. Other small players are also interested but will have to form an open ecosystem to move more safely. The large vendors are being pushed into this architecture, but they are advancing with moderate steps.

Altice Labs is working in this area to develop an open and integrated RU with the PON portfolio and try to take advantage of the opportunities mentioned here, particularly for small cells and 5G densification.

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# Acronyms

| | |
|---|---|
| **5GC** | 5G Core |
| **5G-NR** | 5G New Radio |
| **ADC** | Analog-to-Digital Converter |
| **ANT** | Antenna |
| **BBU** | Baseband Unit |
| **CAT7 A** | Category 7 A cable |
| **CFR** | Crest Factor Reduction |
| **CoMP** | Coordinated Multi-Point |
| **COTS** | Commercial Off The Shelf |
| **CP** | Control Plane |
| **CPE** | Customer Premises Equipment |
| **CPRI** | Common Public Radio Interface |
| **C-RAN** | Cloud Radio Access Network |
| **CU** | Centralized Unit |
| **DAC** | Digital-to-Analog Converter |
| **DDC** | Digital Down Conversion |
| **DPD** | Digital Pre-Distortion |
| **DU** | Distributed Unit |
| **DUC** | Digital Up Conversion |
| **eCPRI** | enhanced Common Public Radio Interface |
| **eMBB** | enhanced Mobile BroadBand |
| **EPC** | Evolved Packet Core |
| **EVK** | Evaluation Kit |
| **F1** | Functional split interface of 3GPP between the CU and DU |
| **F1-C** | F1 Control Plane |
| **F1-U** | F1 User Plane |
| **FH/1588** | Fronthaul / PTP 1588 |
| **FHGW** | Fronthaul Gateway |
| **FPGA** | Field Programmable Gate Array |
| **gNB** | Next Generation NodeB |
| **Hi/Low PHY** | Higher/lower part of Physical layer |

| | |
|---|---|
| **HLS** | High Layer Splitting |
| **iDAS** | indoor Distributed Antenna System |
| **IoT** | Internet of Things |
| **L1'/L1"** | Lower/Higher part of the physical layer (L1) of the OSI reference model |
| **L2-NRT** | Layer 2 - Non-Real Time, the data link layer of the OSI reference model communication channel |
| **L2-RT** | Layer 2 - Real Time, the data link layer of the OSI reference model communication channel |
| **L3** | Layer 3, the network layer of the OSI reference model |
| **LLS** | Low Layer Splitting |
| **LNA** | Low Noise Amplifier |
| **LTE** | Long Term Evolution |
| **MAC** | Medium Access Control |
| **mmWave** | Millimeter Wave |
| **MNO** | Mobile Network Operator |
| **MP** | Management Plane |
| **MPSoC** | Multiprocessor System on a Chip |
| **n78** | 3.5 GHz 5G band, or C-band 5G, the most commonly tested and deployed 5G frequency |
| **nFAPI** | Network Functional Application Plataform Interface |
| **NGC** | New Generation Core |
| **NHP** | Neutral Host Provider |
| **NSA** | Non-Stand Alone |
| **O-CU** | Open CU |
| **O-DU** | Open DU |
| **OLT** | Optical Line Termination |
| **ONU** | Optical Network Unit |
| **OPEX** | Operational Expenditures |
| **O-RAN** | Open RAN |
| **ORAN-FH** | ORAN Fronthaul split 7.2 |
| **O-RU** | Open RU |
| **OTIC** | Open Test and Integration Center |
| **PA** | Power Amplifier |
| **PDCP** | Packet Data Convergence Protocol |

| | |
|---|---|
| **PHY** | Physical layer of the OSI reference model |
| **PoE** | Power-over-Ethernet |
| **PON** | Passive Optical Network |
| **PTP** | Precision Time Protocol |
| **QoS** | Quality of Service |
| **RAN** | Radio Access Network |
| **RF** | Radio Frequency |
| **RLC** | Radio Link Control |
| **RoE** | Radio over Ethernet |
| **RRC** | Radio Resource Control |
| **RRH** | Remote Radio Head |
| **RU** | Radio Unit |
| **SA** | Stand Alone |
| **SCF** | Small Cell Forum |
| **SLA** | Service Level Agreement |
| **SME** | Small to Medium Enterprise |
| **SoC** | System on a Chip |
| **SP** | Synchronization Plane |
| **TCO** | Total Cost of Ownership |
| **TDD** | Time Division Duplex |
| **UP** | User Plane |
| **URLLC** | Ultra-Reliable Low-Latency Communication |
| **vCU** | virtual CU |
| **vDU** | Virtual DU |
| **vDU-H/L** | vDU implementing higher/lower layer functions |
| **vRAN** | Virtualization of Radio Access Network |
| **X2 interface** | eNB to eNB 3GPP interface |
| **XGS-PON** | 10-Gigabit-capable Symmetrical PON |
| **xPON** | Designation for several PON technologies |
| **xRAN/O-RAN** | xRAN forum / ORAN Alliance, a world-wide community operating in the RAN industry |

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