altice labs

Enabling 5G private mobile networks

Open RAN; 5G; Private networks; Radio units; 5G testbed

White paper

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Introduction

In the last two years, we were able to testify the importance of communication networks, technologies, infrastructures, and services. While having a significant part of the population confined, the world did not stop, i.e., students were able to keep having classes, many people were able to continue their work from home as if they were on companies' premises, most of the public services kept running, etc. Nevertheless, there are still many functions that need a physical presence. The 5G era of communications will dramatically reduce the number of situations where human presence is required, for example, to keep industries running.

5G private networks will play a significant role in increasing automation, meeting the communications requirements for real-time operations.

We, at Altice Labs, have an important legacy on communication networks and, with 5G, we intend to keep on developing solutions that will contribute to a complete ecosystem, meeting our customer's needs and demands. Altice Labs' strategy for the 5G radio access network (RAN) is to start by targeting small cell solutions that will allow a fast 5G proliferation, which may also be used to enable 5G private networks.

The following sections present the main relevant features for private networks deployment, followed by the different scenarios and main use cases. Then, Altice Labs' 5G private network is introduced as well as its main purposes and future use. Lastly, an overview of the potential evolutionary path of Altice Labs' 5G radio units based on the chosen platform is provided.

Relevant 5G characteristics for private networks deployment

The advent of 5G has enabled a wave of new applications and use cases in the field of communication technologies, especially for vertical industries. There is, therefore, a growing trend of companies moving forward to build their own private/dedicated 5G networks, taking advantage of the 5G features and specificities that benefit the implementation of such networks, namely, the increased throughput rates, reduced latency, security, and efficiency advantages.

As highlighted in **Table 1**, today's growing enterprise needs, when it comes to communications, are mainly focused on requirements such as enhanced coverage and control capabilities, increased performance, reliability, and flexibility of its communication networks.

Coverage & Control	Enterprises need improved coverage while maintaining control of data and user policies. Specifically, the ones with a large number of locations, distributed across the nation and into rural areas, with a growing number of devices and users.
Performance & Reliability	The increasing number of users and devices requires reliable and high-performing connectivity depending on their needs. Considering that machine-to-machine communication has less limitations compared to human capabilities, serving the true potential of machines requires a more robust link between them.
Operational Flexibility & Integration	Every enterprise has different needs and resources; therefore, they expect flexibility in choosing which operational model works for their needs. The ability to integrate with their current IT infrastructure is also important for lessening the complexity of operations and maintenance.

Table 1 – Enterprises' requirements for communication networks [1]

Alongside the Industry 4.0 deployments, mobile networks are regarded as the main wireless networking option for the broad field of applications, ranging from warehouse and factory floor automation to autonomous vehicle support or logistics, and much more. Of particular interest to private enterprises is the option to deploy mobile networks that are exclusive, or even propriety, of such enterprises, allowing all the devices that operate within the network to be a part of a closed (and isolated, if necessary) network environment. Such private or dedicated mobile networks are becoming an element of paramount importance in enabling enterprises to attain some crucial business drivers, e.g.:

- Minimization of production downtime by taking advantage of highly scalable and reliable networks, possibly with availability service level agreements (SLA);
- Increased flexibility and productivity/quality maximization, benefiting from the guaranteed high

bandwidth wireless connectivity across all enterprise environments, e.g., supporting the use of high-resolution machine imaging;

- Highly reliable critical real-time monitoring, decision-making and control applications enabled by (ultra) low latency network infrastructure, along with edge processing capabilities;
- Protection against security and privacy threats to enterprise networks, provided by new generation wireless mobile communications technologies, with advanced security features.

There are key aspects of the 5G technology that led to significant improvements in the implementation of private networks.

Firstly, as seen in **Table 2**, the concept that 5G networks go way beyond the "one size fits all" paradigm of legacy mobile communication technologies, offering three different and broad types of services: enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC). These services provide the much-needed flexibility to design private networks that are specifically tailored to the needs of each use case.

Massive Machine-Type Communications (mMTC)	Ultra-Reliable Low Latency Communications (URLLC)	Enhanced Mobile Broadband (eMBB)
• Very high device density • Extended coverage range including deep in-building • Battery life extending to multiple years • Low data rate (1 to 100kbps) • Variable (non-critical) latency • Limited mobility (particularly with NB-IoT) • Low device cost	• Under 1 millisecond air interface latency for small data packages • Ultra-reliable communications with 99.999% or better success rate • Low to medium data rates (50kbps to 10Mbps) • Supports high-speed mobility	• Supports at least 100Mbps user rates • Peak data rate of 10 to 20Gbps • High-speed mobility of 500km/h • Up to 15Tbps/km^2 downlink and 2Tbps/km^2 uplink area traffic capacity

Table 2 – Enterprises' requirements for communication networks [1]

Additionally, the 5G radio interface redesign allows the coexistence of multiple service types, sharing the same radio channel and being delivered to different devices. This flexibility, coupled with the concept of network slicing, provides private 5G networks an extreme potential of optimization to tune the network characteristics to the needs of each industry use cases or applications.

Also, an important concept on which 5G technology builds upon is edge computing, which leverages the ability to allocate several resources (or/and industrial enterprise sub-systems) closer to the edge of the (private) network, to transfer, store and process large volumes of data. This provides the ability to reduce the end-to-end latency and add security and privacy benefits by keeping the information closer or within the enterprise premises.

Another marked difference from legacy mobile communications technologies, and increasingly viewed as a must-have feature for future network deployment and management, is the concept of open networking (open interfaces and protocols). O-RAN ALLIANCE is transforming the radio access networks industry towards open, intelligent, virtualized, and fully interoperable RAN. Gaining momentum in 5G networks, open networking provides the mobile network operators (MNO) and private enterprises a much broader choice for private networking deployment, evolution and interoperability options, and the opportunity to seek benefits in the total cost of ownership (TCO) reduction, by combining open interfaces with virtualization capabilities (as presented in **Figure 1**):

- **Open interfaces –** Broader choice in private networking deployment, evolution, and interoperability options;
- **Virtualization –** Ability for capacity aggregation or 'cloudification' in centralized architectures.

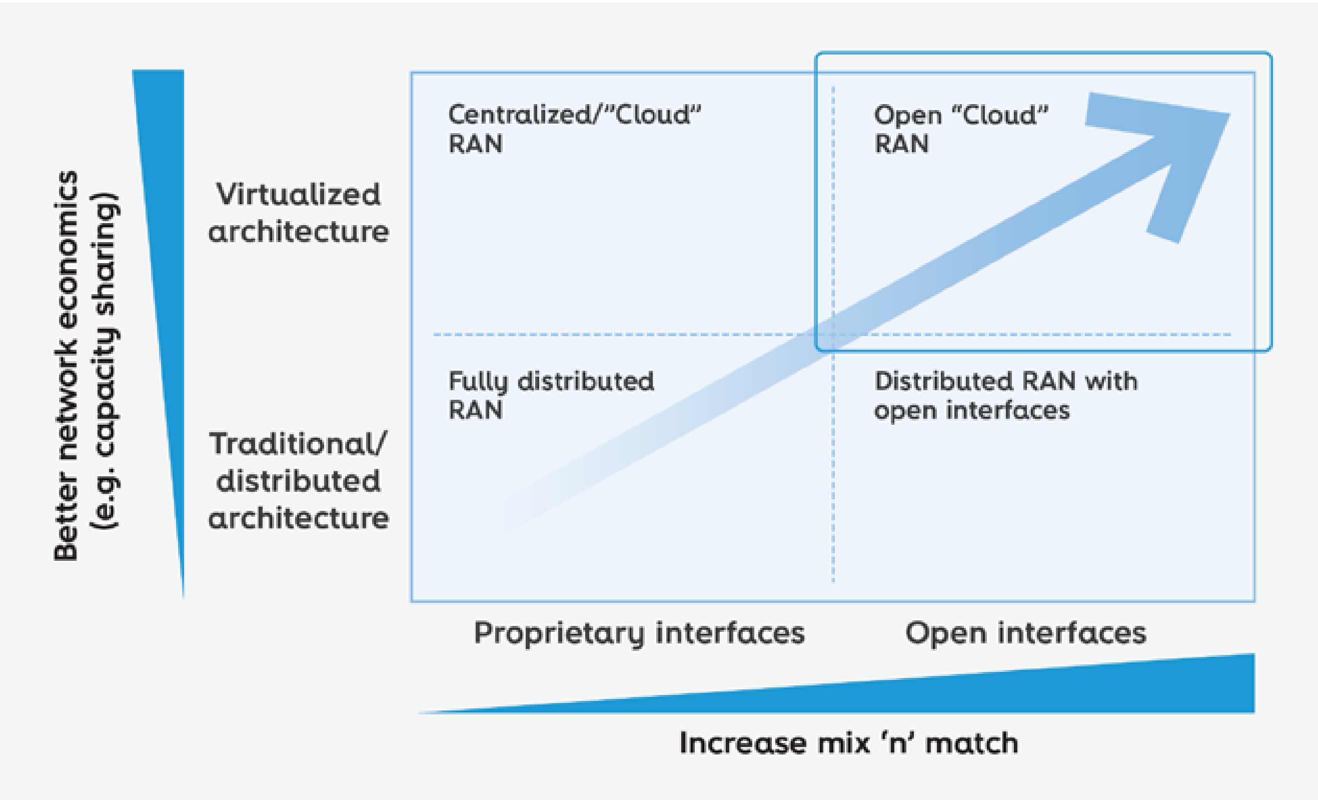


Figure 1 – Interplay between network architecture (traditional or virtualized) and network interfaces (proprietary or open) on RAN type [2]

5G mobile technology-based private or dedicated networks can, thus, offer a set of important benefits when compared to other wired (e.g., Ethernet-based) or wireless (e.g., Wi-Fi or unlicensed spectrum) networks, namely:

Device mobility and deployment flexibility and efficiency while delivering the required network coverage, capacity, and reliability for each use case scenario:

- For eMBB use cases, maximize the achieved data rates, guaranteeing the network characteristics necessary to support, e.g., autonomous guided vehicles (AGV) scenarios, with strict high bandwidth and delay requirements;
- In URLLC use cases, guarantee highly reliable and available communications, with ultra-low latency, in mission-critical scenarios;
- For mMTC use cases, assure the ability to support a very high density of connected devices;
- Implement network slicing to further enhance data security and isolation and provide additional flexibility in the QoS offered across the private networks.

Network bandwidth scaling to the enterprises' needs, without a strict dependence on public MNO roll-out and expansion plans.

Flexibility on the ratio between the uplink and downlink bandwidths, taking advantage of 5G new radio (NR) interface and time division duplex (TDD) deployment options, to carve the private networks to specific needs (e.g., use cases of image/video processing for autonomous vehicles or factory automation where the uplink bandwidth requirement can surpass the downlink).

Latency reduction, taking advantage of local edge processing equipment (edge computing), enabling near real-time services.

Increased privacy and security on top of data isolation capability provided by private networks.

The next section discusses various 5G mobile private networks deployment options and/or scenarios. Several use cases from a wide range of application areas that can benefit from 5G private networks are introduced.

5G private networks: deployment scenarios

5G technology allows, e.g., through network slicing, for an operator to dedicate resources of a 5G public network to a particular enterprise to create a "virtual" private network, or for instance, to sublease a part of its spectrum for a third party to deploy and manage its own isolated private network. Regulators are also considering, in some countries, the option to reserve part of the spectrum to be used exclusively for the deployment of such standalone private networks with dedicated and/or proprietary spectrum, taking advantage of the open networking environment (flourishing with 5G technology) that offers added opportunities for viable deployment of such type of private and dedicated networks.

There is, thus, a plethora of options for the enterprises to capitalize on the various benefits offered by 5G technology when it comes to the strategic option for the private network model to be deployed, as shown in **Figure 2**. The decision is often dependent on the enterprise's particular use cases and its preference about the balance in CAPEX and OPEX, its capabilities or willingness to embrace the various tasks related to the deployment and management of a fully private network, the spectrum availability and cost, and the desired necessity and flexibility to control the data and its processing within the enterprise's premises. Each of the following options that are possible, using 5G technology, have specific characteristics that can be more appropriate for particular use cases.

We focus the scope of this article mainly on the options to deploy standalone private 5G mobile networks both via operator spectrum or by using private/proprietary (or/and unlicensed) spectrum. This type of private networks offers the enterprises the advantages of having a fully dedicated network (with the possibility to be completely isolated or to interwork with public mobile networks), leveraging a broad range of spectrum options (either via the mobile operator or by acquiring their own), having full control over the design and deployment phases timelines, as well as the operations and maintenance, radio plan and spectrum allocation tasks. It also offers the ability to outsource any part of the design or management of the private network to some third-party or MNO.

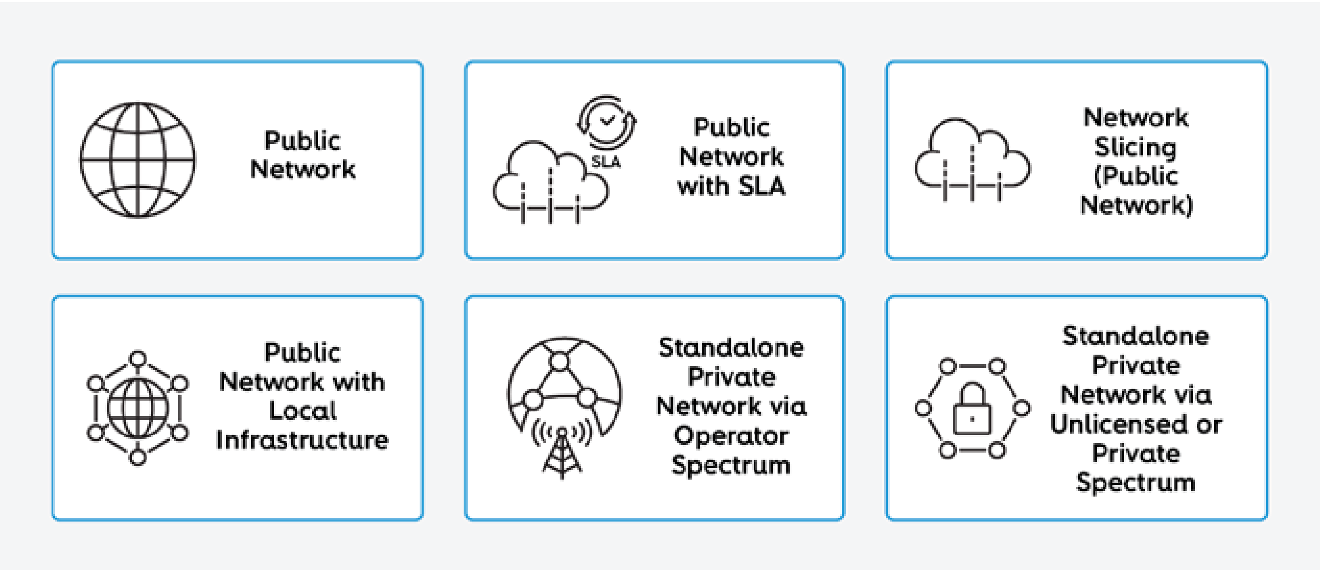


Figure 2 – Range of communication network options for enterprises (public networks to private/dedicated networks) [2]

Uses cases

Nowadays, private mobile networks usually address the cases of large indoor and outdoor venues where the coverage of general public mobile networks is not appropriate to fulfill the needs of the use cases of enterprises. While the options provided by privately operated long term evolution (LTE) networks, with leased or privately owned spectrum, fixed wireless access and Wi-Fi networks have been the primary option for private network environment deployment. However, there is a range of use cases that will immensely benefit from all the benefits mentioned above of 5G when it comes to mobile private network deployment, spanning a very broad field of applications.

Smart cities, smart facilities and gaming industry

The need for extensive bandwidth, low latency, and seamless interoperability and mobility (or multi-connections) between private-public and private-private networks in smart cities, smart facilities, and gaming industry applications often calls for close interaction and collocation of 5G and Wi-Fi networks to provide the necessary quality of experience and service.

5G-enabled private networks can take advantage of characteristics, such as the support for multi-radio access technology, the split of user and control planes, and the capability to offer different service profiles, among others, to provide the perfect framework to such use cases.

Enterprises working on applications such as smart facilities, smart cities, and the gaming industry can also take advantage of other important 5G capabilities to deploy much more capable private networks that will suit their needs, such as:

- Increased consistency in the offered bandwidth and offered experience, in and out of the office/premises, and the ability to support a higher density of connected devices with seamless mobility (large connected workforce or/and real-time gaming experience)
- Access and mobility optimization across 5G private, 5G public, and Wi-Fi 6 networks
- Enhanced collaborative capabilities taking advantage of increased reliability and decreased latency to enable the use of high-definition multimedia and augmented and virtual reality (AR/VR), as well as closed-loop artificial intelligence/machine learning (AI/ML) processing for increased efficiency and quality

Large facilities like airports are a perfect example of such applications. Recently, Groupe ADP, together with their subsidiary Hub One revealed the intention to deploy, in cooperation with Air France, a private 5G network to serve the three large airports in the Paris area, providing high-quality connectivity to more than 120 000 employees, supporting, e.g., voice, data and video communication services, emergency services, and luggage tracking [3].

Manufacturing industry, retail robotics, automated deployments and logistics

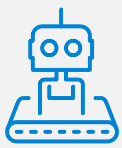
The manufacturing industry encompasses a wide range of use case scenarios, supporting autonomous guided vehicles, automated and remotely operated devices (like inventory robots or forklifts), and several different asset tracking and inventory and logistics management tools, where the user data transmission requires ultra-low latency and high reliability, both downlink and uplink. When implementing a private networking environment, these requirements and constraints make the option for 5G technology the most suitable one.

Additionally, the manufacturing industry can also take advantage of 5G-based private or dedicated mobile networks to provide high-bandwidth, latency-sensitive, and secure transmissions to support the use of high-definition video cameras, either for error detection, quality control, or for life-threatening incident identification.

It is, thus, of paramount importance to take advantage of all 5G features to provide this manufacturing vertical with all the necessary means to achieve a private networking solution that can answer the challenges during the entire production cycle, namely:

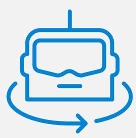
Supply chain

AI-based goods inspection; AGV support



Assembly

Remotely operating devices and AR-guided assembly support



Testing

AR product inspection, AI-based quality control and error detection, automated functional testing support

A particular example of 5G private networks applied to the manufacturing industry and to the advent of Industry 4.0 is the large automotive manufacturer Mercedes-Benz implementation of its own private 5G network in “Factory 56”, aiming to maximize connectivity and link rates across the connected devices and to closely track the complete assembly line in real-time, providing the needed flexibility and response times in its manufacturing process [3].

Remote healthcare applications

During the last decade, there has been an added effort to bridge the communications and connectivity advances with the increased demand for remote healthcare applications. In particular, the recent global pandemic has put significant pressure upon this need to maintain and enhance both critical and routine healthcare operations while guaranteeing maximum safety for patients and front-line healthcare workers.

Additionally, 5G private network characteristics (e.g., very low-latency and high-bandwidth) can also enable this sector to take advantage of VR in several healthcare applications, such as dentistry or other hospital practices, to diminish patients' discomfort or give better assistance in pain management and recovery procedures.

Even before the COVID-19 pandemic, 5G private networks were already being considered as an option to provide hospitals with high-performance connectivity. For example, in 2019, Rush Medical Center, in Chicago, started to deploy a 5G technology-based private network with the rationale of replacing all cabled connectivity in their premises to attain savings in operation and maintenance while guaranteeing the added flexibility and performance of wireless 5G connectivity [3].

These use cases show the potential and wide range of application scenarios of 5G in private networks.

Altice Labs' 5G private network

Following the growing interest in 5G private networks, Altice Labs naturally aims to be involved in the development of state-of-the-art communication platforms and products that can leverage the advent of 5G.

Thus, taking advantage of the recent work developed under the Mobilizador 5G project , together with the Instituto de Telecomunicações of Aveiro (IT-Aveiro), the University of Aveiro (UA) and on technical meetings with MEO teams, Altice Labs planned the development and deployment of a small cell 5G private network that can be used as a live platform to:

- streamline various uses cases related to 5G, providing a real basis for experimentation;
- gain relevant knowledge and experience for the next generation of Altice Labs' portfolio;
- be a storefront for future customers.

Altice Labs' 5G private network, aimed at both indoor and outdoor environments in the Aveiro Campus (depicted in **Figure 3**), will serve as a testbed for experimental research and new product development, either for applications or network elements in the B2B segment (e.g., IoT, uRLLC). This solution will feed small cells served by 5G radio units (RU), not only in Altice Labs' campus, but also the 5G RU from the STEAM City [4], 5Growth [5], and 5G-VINNI [6] projects.

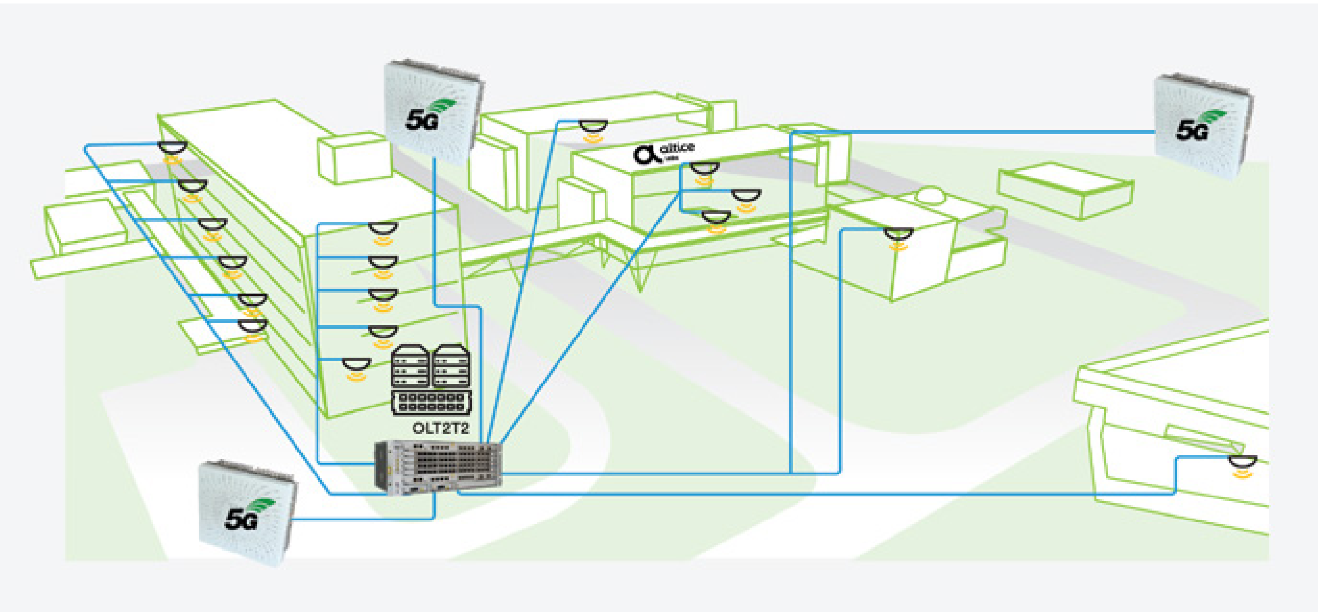


Figure 3 – Geographical distribution of 5G radio units in Altice Labs' campus

Figure 4 presents the high-level design of this project that is being developed in several phases until it finally reaches the overall and complete project design.

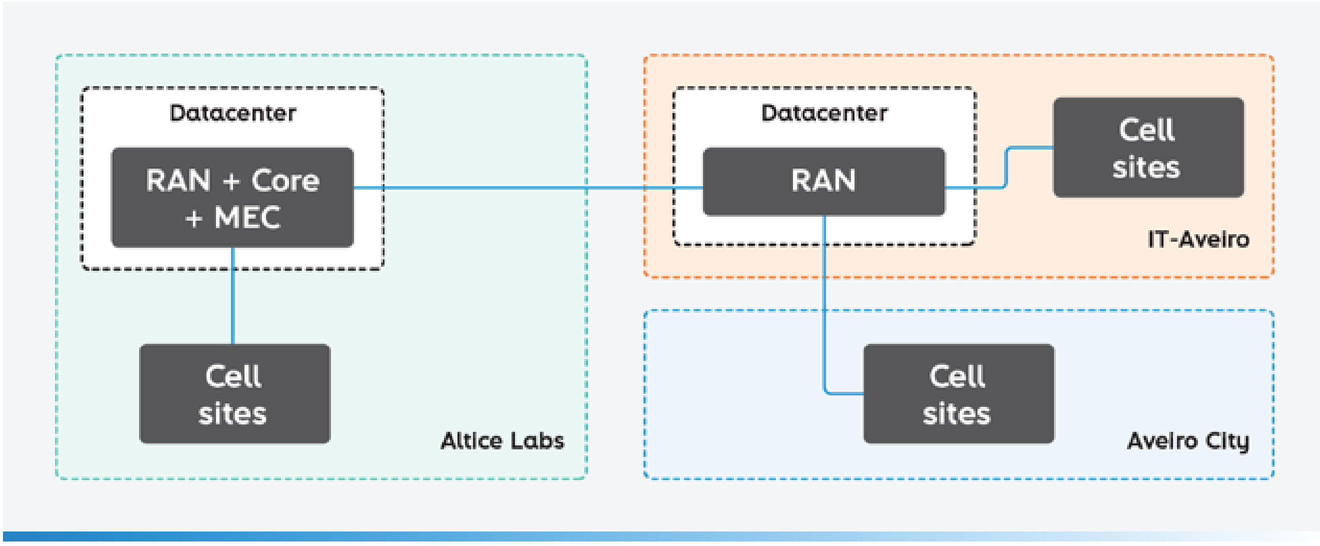


Figure 4 – High-level design of private network

Since the majority of the fronthaul transport connections require dark fiber, one important technical decision was to have the distributed unit (DU) functions also located at the IT-Aveiro datacenter (in addition to the DU located at the Altice Labs' central office) to connect the 5G radio units from STEAM City and 5Growth projects. With this approach, the required dark fibers between IT-Aveiro and Altice Labs to feed the various RU could be reduced from tens of dark fibers to only two to interconnect the DU with the centralized unit (CU).

The 5G network design follows the O-RAN architecture splitting the RAN protocol stacks through the components: O-RAN centralized unit (O-CU), O-RAN distributed unit (O-DU), and O-RAN radio unit (O-RU). The fronthaul (between O-DU and O-RU) adopts the split 7.2x specified by O-RAN, which divides the physical layer function, where the High Phy functions reside in the DU, and Low Phy ones reside in RU.

This split 7.2x, as an open and standardized interface, can bring additional benefits for the 5G small cell solution, namely:

- increased interface simplicity and lower RU complexity, reducing the function set present in the RU and allowing for a more compact and easier-to-deploy solution (one box);
- interoperability capabilities with other manufacturers/vendors and further user data transfer optimization;
- maximized future proofness of the solution:
  - placing most functions at the DU allows new features via software upgrades without the need for HW changes at the RU;
  - allows for simplified implementations of advanced functions such as beamforming and inter-cell coordination;
  - capable of working in non-standalone (NSA) and standalone (SA) scenarios;
  - reduced site rental fees, maintenance costs, and power consumption of the RU in 5G greenfield and hotspot areas.

In the project's first phase, the fronthaul interfaces, presented in **Figure 5**, will be deployed using direct optical connections between O-DU and O-RU due to challenging requirements in terms of throughput, latency, and jitter.

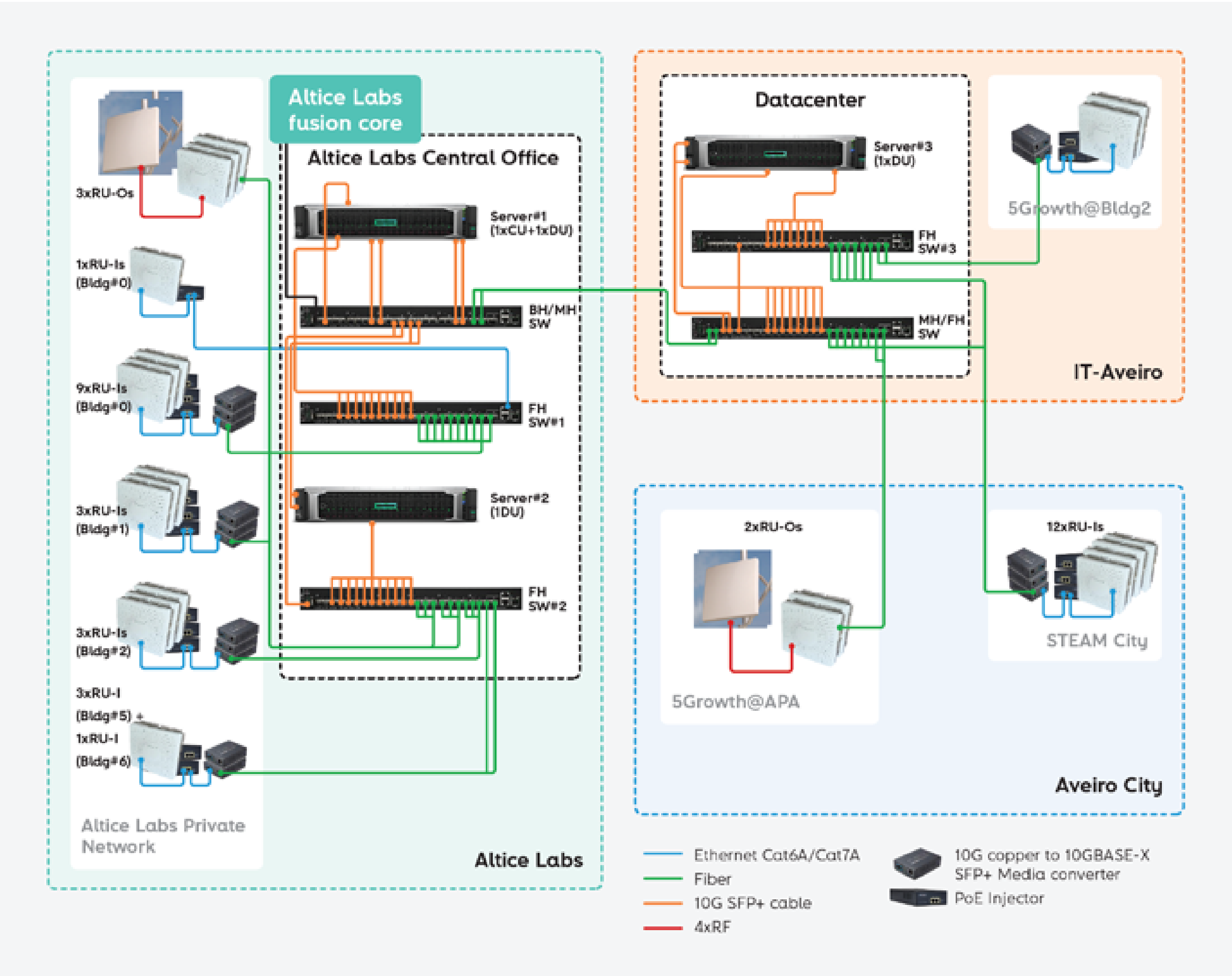


Figure 5 – Detailed design of Altice Labs' private network interconnections

However, in a real-world scenario, the adoption of dark fibers for fronthaul interfaces is not the most efficient approach due to the cost and the quantity of fibers needed to interconnect all the RU. There are different solutions for the transport network to support an xHaul architecture, either solely using packet-switched solutions (deployed from cell site to core network, e.g., MPLS, Ethernet, or IP-based) or mixing it with other technologies (e.g., xWDM, PON, DOCSIS or microwave radio links in the access to devise the end-to-end network).

While any access topology could be used for fronthaul, topologies with a limited number of transit transport network elements – hub-and-spoke or spine-and-leaf – leave more room for latency/delay budget, allowing the extension of fronthaul over larger distances. For midhaul/backhaul interfaces, the requirements regarding latency budgets are not so strict, so any access topology (ring, chain, or hub-and-spoke/spine-and-leaf) can be used without special considerations.

Packet-switched solutions might offer more advantages in terms of QoS guarantees, but other technologies can be used for the xHaul architecture. Different guidelines and trade-offs should be considered, depending on the choice of used technologies.

All these evolutionary approaches are to be considered, by Altice Labs, in the future to deploy this type of private 5G network. The focus, at this stage, is to present a solution as agnostic as possible regarding the transport technology, to be prepared for being supported (fronthaul, midhaul, or backhaul) in any of these mediums.

Additionally, and focusing on capitalizing further on the 5G technology, Altice labs is also developing its own 5G RU. This product can either be incorporated in this 5G private network solution or be used as an RU to be integrated with any other solution, guaranteeing its interoperability by following the O-RAN ALLIANCE standard.

The following section focuses on the potential applications and future evolutionary path of the Altice Labs' RU product and the platform upon which it is developed within the 5G technological panorama.

Altice Labs' evolutive access network solution

The 5G RU platform developed is based on three main features, enabling its customization for distinct deployment scenarios, being an evolutive solution for public or private access networks [7][8][9]:

Flexible radio-frequency hardware, capable of operating in multiple bands, individually or simultaneously, allowing the transmission and reception of wideband multi-standard signals with different levels of multiple-input and multiple-output (MIMO) in the antenna elements.

Hybrid computational platform consisting of a heterogeneous set of resources, including multicore general-purpose processors, programmable logic fabric, and hardwired blocks, and allowing the flexible hardware-software partitioning of the system implementation.

Configurable fronthaul interface, from the network connection to the transport protocol implementation, permitting the utilization of several cable- or fiber-based transmission media, including dark fiber and PON-based solutions, with redundancy extensions.

These capabilities make the developed product an evolutive platform that can be easily customized to deploy a complete product portfolio for 5G RAN, backward compatible with 4G and other types of communication, while simultaneously promoting the research on next-generation networks. The supported bands and waveforms, the RAN functional split, the fronthaul interface, the compression method, and other features can be easily configured by simple unit reprogramming. Moreover, customization, upgrade, and optimization of the 5G RU can be performed, statically or dynamically, locally or remotely in the field, as most of the features are supported by a reprogrammable system-on-chip that can be managed by the central office. Thus, the maintenance and upgradeability costs of the solution in the context of dense private networks are minimized.

The flexible radio-frequency hardware capabilities can support, on the same physical platform, 5G NSA and 5G SA deployments, LTE-NR and NR-NR dual connectivity, NR carrier aggregation and dynamic spectrum sharing, through the software programming of the radio-frequency frontend and hardware reconfiguration of the digital and fronthaul interface modules.

Also, the reconfigurable features of the hybrid computational platform make feasible the instantiation of the functions strictly required, as well as the integration of several techniques, such as crest factor reduction and digital predistortion to decrease the signal's dynamic range and linearize the power amplifiers of the transmission chains, allowing the implementation of energy/power consumption saving features.

Besides, the configurable fronthaul interface permits the implementation of several RAN architecture splitting options, including 4 and/or 7, making possible the co-localization of the RU, the DU, and, in some circumstances, also the CU. This feature paves the way to the integration of edge computing and, later, to support URLLC services, benefitting from the computational capabilities of the platform.

The multi-band and multi-standard capabilities, together with the platform's hardware re-programmability and software embedding features, support different generations and classes of IoT communications, including mMTC, IoT, NB-IoT, cellular IoT services, as well as vehicle-to-everything communications (V2X).

The reconfigurability of the platform allows the deployment of optimized RAN sharing solutions, including static or dynamic network slicing.

An important aspect for localization services is the development and integration into the platform of the physical layers for the supported waveforms. It allows the low-level processing (e.g., timestamping, detection, etc.) of signals that can be used for such purposes, which considerably improves the accuracy, compared to approaches based on higher layer information, without adequate physical layer support.

Finally, the flexibility and programmability of the developed platform allow its usage in testbeds for next-generation networks, with new approaches based on ML showing promising results and that can benefit from a parallel implementation of AI algorithms into the configurable hardware resources and multicore software implementation.

Conclusions

This article presented an overview of the main aspects that 5G will bring to the private networks. The main characteristics of 5G that make it interesting to be used in private networks were reviewed, followed by the presentation of several approaches to build 5G private networks, and pointing out the main differences between them. The article then presented possible use case scenarios for 5G private networks.

Altice Labs' 5G private network currently being deployed at Altice Lab campus, with extensions to the IT-Aveiro and UA and, in the future, to several spots in the city of Aveiro, was presented in detail, including several layers of design. The main goal for this infrastructure is to test, validate and demonstrate 5G technologies and services (use cases) that are especially attractive with 5G private networks.

At last, since this network is partially built using Altice Labs' 5G RU, specially targeted for small cells scenarios, we presented the potential of this product and the plans for its future evolution.

References

[1] "5G technologies in private networks," 5G Americas, October 2020. [online]. Available at: https://www.5gamericas.org/wp-content/uploads/2020/10/InDesign-5G-Technologies-for-Private-Networks-WP.pdf

[2] "5G IoT Private & Dedicated Networks for Industry 4.0," GSMA, October 2020. [online]. Available at: https://www.gsma.com/iot/wp-content/uploads/2020/10/2020-10-GSMA-5G-IoT-Private-and-Dedicated-Networks-for-Industry-4.0.pdf

[3] "The Growing Case for Private 5G Networks," NEC Insight, March 2021. [online]. Available at: https://www.nec.com/en/global/insights/article/2021030002/index.html

[4] Aveiro Steam City Project https://www.cm-aveiro.pt/inovacao/aveiro-steam-city

[5] 5Growth European Project (5G-enabled Growth in vertical industries) https://5growth.eu/

[6] 5G-VINNI Project (5G Verticals INNovation Infrastructure) https://www.5g-vinni.eu/

[7] "Zynq® RFSoC DFE" product brief," Xilinx, Inc. [online]. Available at: https://www.xilinx.com/content/dam/xilinx/publications/product-briefs/xilinx-zynq-dfe-product-brief.pdf

[8] "Zynq® RFSoC DFE Backgrounder," Xilinx, Inc. [online]. Available at: https://www.xilinx.com/content/dam/xilinx/publications/backgrounders/zynq-rfsoc-dfe-backgrounder.pdf

[9] "FPGA vs ASIC: 5G changes the equation," Xilinx, Inc. [online]. Available at: https://www.xilinx.com/publications/reports/mobile-experts-market-report.pdf

Acronyms

10GBASE-X	Part of the IEEE 802.3 10 Gigabit Ethernet family of standards
4G	Fourth generation mobile networks
5G	Fifth generation mobile networks
5Growth	5G-enabled Growth in Vertical Industries, an EU funding project
5G-VINNI	5G Verticals InnoVation Infrastructure, an EU funding project
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AR	Augmented Reality
APA	Administration of the Port of Aveiro
B2B	Business-to-Business
BH	Backhaul
CAPEX	Capital Expenditures
CU	Centralized Unit
COVID-19	Coronavirus disease 2019
DOCSIS	Data Over Cable System Interface Specification, an international telecommunications standard
DU	Distributed Unit
eMBB	enhanced Mobile BroadBand
FH	Fronthaul
High Phy	Higher part of the Physical layer of the OSI reference model
HW	Hardware
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
IT-Aveiro	Instituto de Telecomunicações of Aveiro
Low Phy	Lower part of the Physical layer of the OSI reference model
LTE	Long Term Evolution
MEC	Multi-access Edge Computing
MEO	Mobile and fixed telecommunications service and brand from Altice Portugal
MIMO	Multiple-Input/Multiple-Output
ML	Machine Learning

mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MPLS	Multiprotocol Label Switching
MH	Mid haul
NB-IoT	Narrow Band IoT
NR	New Radio
NSA	Non-Standalone
O-CU	Open CU
O-DU	Open DU
OPEX	Operational Expenditures
O-RAN ALLIANCE	Global community of more than 300 companies operating in the RAN industry
O-RU	Open RU
PoE	Power-over-Ethernet
PON	Passive Optical Network
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RU	Radio Unit
SFP+	10Gbps Small Form-factor Pluggable
SLA	Service Level Agreement
SW	Switch
SA	Stand Alone
STEAM City	Urban Network for Upgrading STEAM Skills and Increasing Jobs Added-Value through Digital Transformation in a new economic context, an EU funding project
TCO	Total Cost of Ownership
TDD	Time Division Duplex
URLLC	Ultra-Reliable Low-Latency Communication
UA	University of Aveiro
V2X	Vehicle-to-everything
VR	Virtual Reality

Wi-Fi	IEEE 802.11x - Wireless Network (Wi-Fi Alliance)
Wi-Fi 6	IEEE 802.11ax, the sixth generation of the Wi-Fi standard
xHaul	Converged optical and wireless network solution able to flexibly connect small cells to the core network
xWDM	The technology of wavelength-division multiplexing

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