An e-health use case enabled by private 5G, AR and Edge Computing

E-health; Surgery; Augmented Reality; Private 5G; Edge Computing

White paper

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Introduction

The patient lies on the surgery table, surrounded by lights and robotic arms, each specialized in a task. He is being monitored by contactless sensors, with collected data being analyzed in real-time by local and remote powerful and complex AI systems.

Even if highly autonomous in their decisions and acts, more detailed and crucial actions are performed or, at least, authorized by remote human specialists, monitoring the process via a holographic 3D model of the damaged organ to be intervened.

5G was conceived with the objective of expanding the previous mobile cellular networks footprint, targeted at the consumer market, now looking at the business market. With that objective in mind, 5G has been instrumented with the required capabilities to transform businesses, industries, and societies, with no limit on sectors that this emerging technology can impact.

The health sector has always been a highly technological area, adopting the most recent developments to provide better and more efficient services. Recent 5G developments have the potential to bring online healthcare closer to patients, at home, on the move, or at hospitals, with better, personalized services, thus better reaching the population at lower costs. 5G per se is of limited usefulness without end systems, services, and applications that exploit the enhanced provided connectivity. Complemented by well-positioned edge computing platforms, for which 5G provides native integration, use cases with strict requirements in relation to latency, resiliency, and data protection, become feasible. And connected healthcare, going beyond data collection from sensors for offline analysis, is demonstrating the first results, as shown here with the adoption of Augmented Reality (AR).

According to recent projections, 5G-powered healthcare applications will add US $530 billion to the global GDP by 2030 [1]. That will be achieved with the adoption of 5G in the several domains and stages of e-health activity, as presented below. One example of such adoption is the focus of this document.

5G for verticals

5G differentiating characteristics

5G aggregates in a single technology all the characteristics to answer users' and industry-specific and most demanding connectivity requirements. Operation at higher frequencies (above 24GHz), a denser deployment of cells and advanced mechanisms like multi-user multiple-input/multiple-output (MU-MIMO), grants 5G with higher throughput (up to 20Gbps) when compared with 4G. Due to a more efficient control plane, terminal's mobility can also be higher, up to 500km/h, providing support to drones, air transport, and high-speed trains. These improved features will be mainly exploited by the B2C market, guaranteeing a better user experience.

However, 5G is also able to operate at lower frequencies (below 1GHz). This capability guarantees broader and deeper coverage, even if with lower bandwidth, and 5G systems can connect a larger number of simultaneous devices (up to 1 million per square kilometer) and active connections, while enabling low power consumption by connected equipment, welcoming massive IoT. But 5G really differentiates in the capacity to provide ultra-low latency at radio level (down to 1ms) and high reliability (up to 99.9999% availability), paving the way for ultra-reliable and low latency communications (URLLC) for critical IoT. Security has also been enhanced at all the communications layers [2]. Non-Terrestrial Networks (NTN), covering 5G over satellite, non-public networks (NPN), i.e., 5G network deployment at the private domain, operation in unlicensed spectrum, native integration of edge computing (EC), support for mission-critical communications, and operation under sub-normal conditions, are just some other features added or improved with 5G.

These differentiating aspects address the B2B market demand for a flexible, unifying technology able to support their most challenging use cases, in all sectors of activity, like transportation, manufacturing, agriculture, and health. They represent a new era in mobile broadband communications, expanding into business applications besides individuals. These have been progressively introduced in 3GPP Technical Specifications from releases 15 to 17, from June 2019 to June 2022. The following releases will improve 5G functionalities and performance, leading to 6G in release 21, expected in 2028.

As mentioned above, edge computing is fundamental for 5G by placing computing resources and services closer to the network accesses and contributing to achieving the required low latency, reliability, load distribution, and data sovereignty required in many industrial applications.

Non-public Networks

Non-Public Network, or NPN, is the 3GPP designation for 5G systems intended for private use. Meant for the sole use of a private entity, such as a seaport community, a factory, or a hospital, it may be deployed in a variety of configurations, utilizing both virtual and physical elements. Two main models for NPN deployment exist, standalone NPN (SNPN) and Public Network integrated NPN (PNI-NPN).

While SNPN instantiates complete 5G systems at the premises of a private entity (physical NPN), PNI-NPN are deployed with the support of an operator network (Public Land Mobile Network - PLMN) by means of dedicated data networks and/or by one or more network slice instances allocated to the NPN (virtual NPN), as depicted in **Figure 1**.

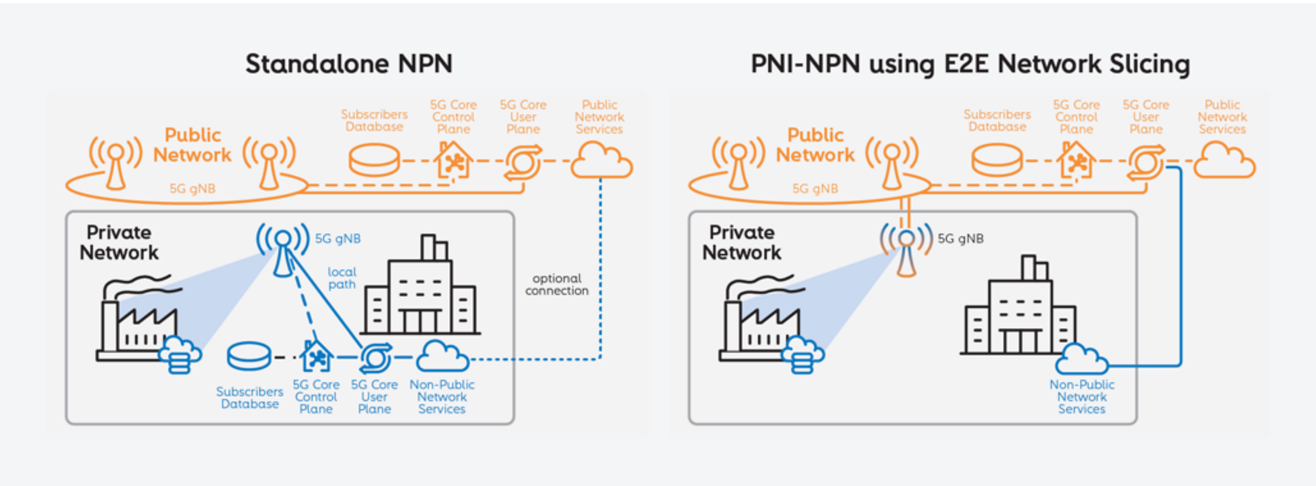

Figure 1 – NPN deployment flavors (5G-ACIA)

SNPN can be tailored to the organization's dimension, complexity, and requirements while keeping data isolation for the sake of performance, security, privacy, and safety. It guarantees maximum technology exploitation for ultra-high-performance applications. However, dedicated 5G equipment and radio spectrum lead to higher costs for both CAPEX and OPEX.

On the other side, with PNI-NPN being based solely on the instantiation of virtual entities, potentially with no local, dedicated infrastructure, costs are reduced and distributed among customers (no CAPEX for the customer other than terminal equipment). It provides quick and easy deployment, expansion, and reconfiguration, the possibility of having global coverage provided by the PLMN, and easy roaming between the private domain, the public domain, and other networks. There is no need for a dedicated 5G spectrum, which is shared with other PNI-NPN and the public service. For the operator, it is a single network to configure, provision, and monitor, reducing customer OPEX.

An intermediate configuration exploits the 5G control and data planes separation. Individual data planes for each industrial client are kept in their private domain, while the control plane is deployed at the service provider,

maybe at the edge, being shared by different customers. However, while those scenarios are not mature enough, and standalone 5G PLMN are not widespread, the SNPN model is the one that is currently being mostly adopted.

The adoption of 3GPP technology (4G and 5G) for the realization of private communications networks has recently seen significant growth, with hundreds of networks installed globally [3] following the SNPN model. Although still with a smaller presence, 5G is the main driver of this growth, given its differentiating characteristics, as seen above. A recent study by Bloomberg [4] indicates that the market for 5G private networks will represent, in 2030, US $36 billion, with a compound annual growth rate (CAGR) of 47.5% until 2030. The relevance of NPN is also expressed in an "*NTT study of roughly 200 senior leaders across Germany, Japan, the United Kingdom, and the United States that found that 90% expect private 5G to become the standard network of choice in their industry within five years, with 80% planning to deploy private 5G networks within the next 24 months*" [5].

Currently, the market offer of 5G components to set up complete NPN is extensive and is growing. In markets where 5G spectrum is available for industry usage, private entities have the possibility to deploy 5G systems on their own. However, planning, installing, configuring, and operating a private mobile cellular network, requires specific experience, qualifications, and tools that largely exist at operators. Having experienced teams and the right tools to support 5G networks' operation is fundamental when critical and demanding services are to be run over those networks, where a malfunction will have a strong impact on the business. Thus, besides developing its own NPN networking technology, Altice Labs is also evolving its network operations support systems to address this emerging business opportunity and help verticals focus on their businesses.

5G and healthcare

Healthcare is evolving and becoming predictive, preventive, personalized, and participatory. These are the basis of the '4P' medicine concept (personalized, preventive, predictive, participatory), where communications, data collection, and processing play a central role. Thus, similarly to other verticals, the health sector ecosystem benefits from 5G adoption.

A whitepaper from the 5G Health Association [6] summarizes 5G aspects relevant to 20 identified medical use cases, as shown in **Figure 2** [7].

KPI	UE Data Rate	End-to-End Latency	Availability	Reliability	Traffic Density	Connection Density	UE Power Consumption	Coverage	Maximum UE Velocity	Time Error	Security	Network Slicing
KPI in subset of 20 use cases	11	11	16	16	4	8	7	12	5	8	17	13
KPI in use cases (%)	55%	55%	80%	80%	20%	40%	35%	60%	25%	40%	85%	65%

Figure 2 – 5G KPI analysis for medical use cases [7]

Those 20 use cases are organized into five classes, as shown in **Figure 3**.

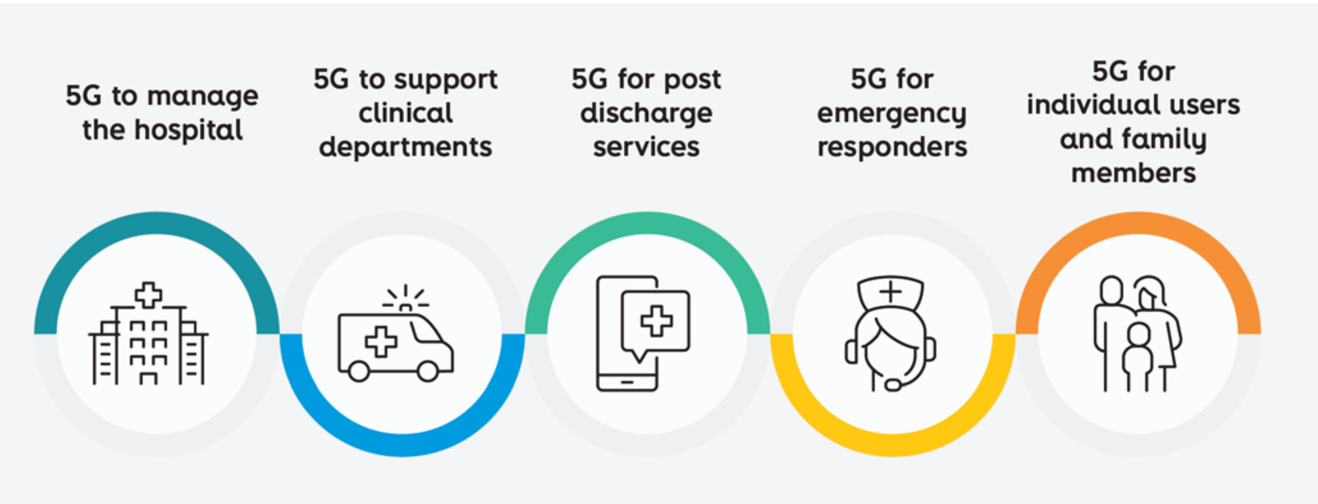

Figure 3 – 5G medical use cases [7]

The same document identifies opportunities and risks of 5G application in medicine (with identified risks not specific to the 5G technology).

Opportunities

- Homogenization of wireless network technologies
- Replacement of wired communication networks
- Fulfilment of previously conflicting data communication requirements
- Relocation of health services and infrastructures
- Increased flexibility for patients when choosing healthcare providers
- Enables continuous patient monitoring, 'white spots' in the monitoring are closed
- Increased resource efficiency
- More convenient access for patients to healthcare providers
- Enabler for distributed real-time AI applications

Risks

- Decline of inter-human interaction
- Missing macroeconomic guidelines
- High investment needs in the technical infrastructure
- In-depth social discussion about the health effects of technology

STL Partners [8] also identifies ten 5G healthcare use cases and maps them into 5G characteristics (see **Table 1**).

Use Case	Low Latency	High Bandwidth	Mobility	Reliability & Security	Capacity
1. Connected ambulance	✓	✓	✓	✓	
2. HD virtual consultations		✓	✓	✓	
3. Remote patient monitoring			✓	✓	✓
4. Video-enabled medication adherence		✓		✓	
5. AR/VR assistance for the blind	✓	✓	✓	✓	
6. Distraction and rehabilitative therapy	✓	✓			
7. Remote expert for collaboration in surgery	✓	✓		✓	
8. AR/VR for training and education	✓	✓		✓	
9. Real-time high throughput computation processing	✓	✓	✓		
10. Video analytics for behavioural recognition	✓	✓		✓	

Table 1 – 5G use cases vs. characteristics [8]

Thus, the adoption of 5G by the health sector is a natural evolution and a consequence of the presented technology characteristics.

5G with edge computing is already creating a connected healthcare ecosystem by leveraging IoT, artificial intelligence and machine learning (AI/ML), and robotics to enhance patient care. When combined with 5G, other disruptive technologies will result in more accurate diagnoses and transform remote patient interactions. Remotely assisted and robotic surgery can be performed by leveraging the interconnectivity of 5G, IoT, and augmented and virtual reality (AR/VR). Medical sensors, complemented by AR and the exchange of real-time data readings, can guide surgeons to perform operations cooperatively.

Both SNPN and PNI-NPN have their own space in the healthcare ecosystem in the scope of the identified use cases. While an SNPN better answers the needs of a hospital, it can conveniently be extended with a PNI-NPN to connected ambulances traveling to and from it. Another PNI-NPN may also be the solution to connect equipment placed at patients' homes in a privileged global virtual 5G network with specific characteristics.

Augmented Reality enabled by 5G and Edge Computing

Augmented Reality (AR) is an interactive experience in a real-world environment, where the seen objects are enhanced by visual and non-visual computer-generated information. The major outbreak to fully disseminate AR technology was the creation of handheld devices. In 2013 Google announced its open beta Google Glasses, and, in 2015, Microsoft announced its AR headset. The following year, AR entered the mainstream map with Pokémon Go (Nintendo gaming creation) tremendous success. And after the COVID-19 pandemic surge, AR remote presence and wireless communications became a daily need for millions of users.

Virtual, augmented, and mixed reality require high levels of graphical rendering to process inputs and generate dynamic contents, providing a computed generated simulation of a real or virtual user environment or adding virtual elements to that real world. Wearable equipment, especially in specific environments such as the medical operating room, shall be light, reliable, and simple to use but efficient and precise at executing simple tasks. Balancing processing tasks between the user equipment and the nearest cloud (via EC) provides a solution for unlimited capabilities in what concerns AR/VR at the cost of bandwidth and low latency. And this is where 5G and EC come to the rescue, posing almost unlimited resources in the processing of 3D content. In [9], different aspects are discussed with the overall conclusion that the "*extremely high bandwidth, ultra-low latency and massive connectivity offered by future 5G systems, envision a promising future for mobile augmented reality (MAR) applications along with the complementing technology MEC*".

Surgical metaverse

Regarding healthcare settings, AR has demonstrated a potential educational application with a wide range of benefits. The concept of real-time information acquisition and data visualization is a foreseen ambition to leverage AR applications in the healthcare sector.

This breakthrough with immersive technologies opened a new era: that of the use of the so-called metaverse in post-graduate medical education. The surgical metaverse can be defined as the access to medical data via augmented, virtual, mixed, and extended reality through a headset within an ongoing surgical procedure and is already considered to be the next-generation mobile computing platform. It will transform the operating room

of the future into an immersive surgical arena and a multimedia space, enabling surgeons to become 'super surgeons' by having real-time access to virtual objects during ongoing surgery.

Although an immediate role for immersive surgical training is available, future developments with advanced computer graphics and high-speed and low-latency broadband communications could enhance human natural vision capabilities beyond what we have ever imagined:

- An immersive experience within the operating room of the future, enhanced by a full digital ecosystem supporting every stage of surgery, from planning to discharge.
- Empower surgical teams with next-generation computing, visualization, and artificial intelligence technology.

Perhaps one of the most expected advanced computer vision tools would be the ability to track real-life objects in an augmented space visualization, making this technology suitable for developing education and AI-assisted guidance systems in surgical scenarios. The new 5G networks will create high-fidelity in the healthcare sector by boosting medical image computer science research with advanced computer graphics capabilities that ultimately will create high-speed/high-resolution images for AR in real-time. A recent systematic review concluded that AR technology readiness level is beyond the testing phase, with clinical use cases becoming more common, like in neurosurgery, urology, gastroenterology orthopedics, and cardiovascular surgery [10] [11] [12] [13] [14] [15].

In 2018, the market for AR in healthcare worldwide was valued at around US $610 million and was projected to exceed US $4.2 billion by 2026 [16]. This represents a compound annual growth rate (CAGR) of 27.4%. In parallel, the breast cancer (BC) market was valued at US $21.58 billion in 2019 and is projected to reach US $55.27 billion by 2027, with a CAGR of 13.1% during the forecast period [17].

The adoption of surgical metaverse can be highly relevant in several scenarios as performing surgery. During that medical act, the surgeon is thoroughly sterilized, with surgical gloves, and unable or limited to access medical data. To better understand its importance, let's look at breast cancer surgery and its clinical needs with a user-centric approach.

The use case described next demonstrates the advantages of AR adoption in the healthcare sector. For this and other use cases, 5G and EC deployment can overcome end-user equipment processing limitations, making AR/VR virtually possible in every terminal.

Use case: AR and e-health

For the first time on May 5, 2022, a novel experiment in breast cancer surgery took place between the Champalimaud Foundation in Lisbon, and the University of Zaragoza, in Spain, during a live medical conference [18], as shown in **Figure 4**. Rogelio Andrés-Luna was in Zaragoza (more than 900 km from the operation site) with a laptop computer that was linked to Pedro Gouveia's HoloLens [19] using dedicated software developed by remAID [20]. That 'remote surgeon' in Zaragoza, despite the considerable physical distance between the two doctors, was able to supervise the 'performing surgeon' in his delicate task in the operating room as if he was right next to him, sharing the same visual field.

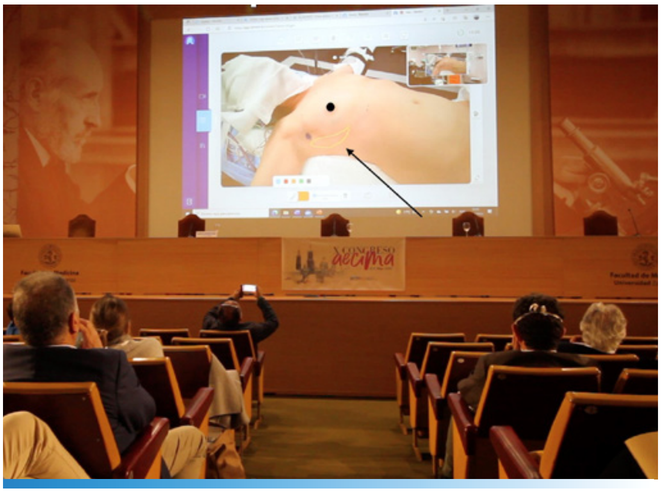

Figure 4 – Audience in the room, following the demo

In the presented use case, two distant surgeons were synchronized through video and sound with reduced latency, thanks to the latest and most powerful broadband technology for transmitting digital information: a private 5G network. But this was not an ordinary videoconference. More than that, advanced computer graphics enabled an augmented reality world within a live remote telementoring (proctoring) breast cancer surgery, meaning that the distant surgeon was able to supervise and anchorage virtual objects, like surgical indications for incision placement, surgical technique, or anatomic structures identification.

This was only achievable thanks to AR, powered by 5G connectivity, through an augmented/mixed reality 'Hololens 2' headset (see **Figure 5**). It enabled a transfer of surgical knowledge from a mentor (specialist surgeon) to a mentee (operating surgeon) in real-time, allowing for high-fidelity in a proof-of-concept experience. This capability allows

Figure 5 – The surgeon with an AR headset in the operating room

the surgeon to interact within a mixed reality view, with computer-generated images blending with the real patient view, where digital content is properly processed without impairing visibility.

For the demo, Altice Labs made available a 5G private network 'in-a-box' composed of servers, switches, a router, and a 5G indoor radio unit (as represented in **Figure 6**). This network provided indirect connectivity (USB tethering via a 5G smartphone) to the doctor's Microsoft HoloLens 2 as these AR glasses do not have native 5G support.

Figure 6 – 5G 'in-a-box' used kit

From an end-to-end perspective, the communication channel was established through the 5G private network, the Champalimaud local corporate network, the Internet, and lastly, the Movistar public 5G network at the other end (see **Figure 7**). Far from being the optimal scenario, it was still possible to achieve a round-trip time (RTT) of 42ms, enough to showcase the scenario.

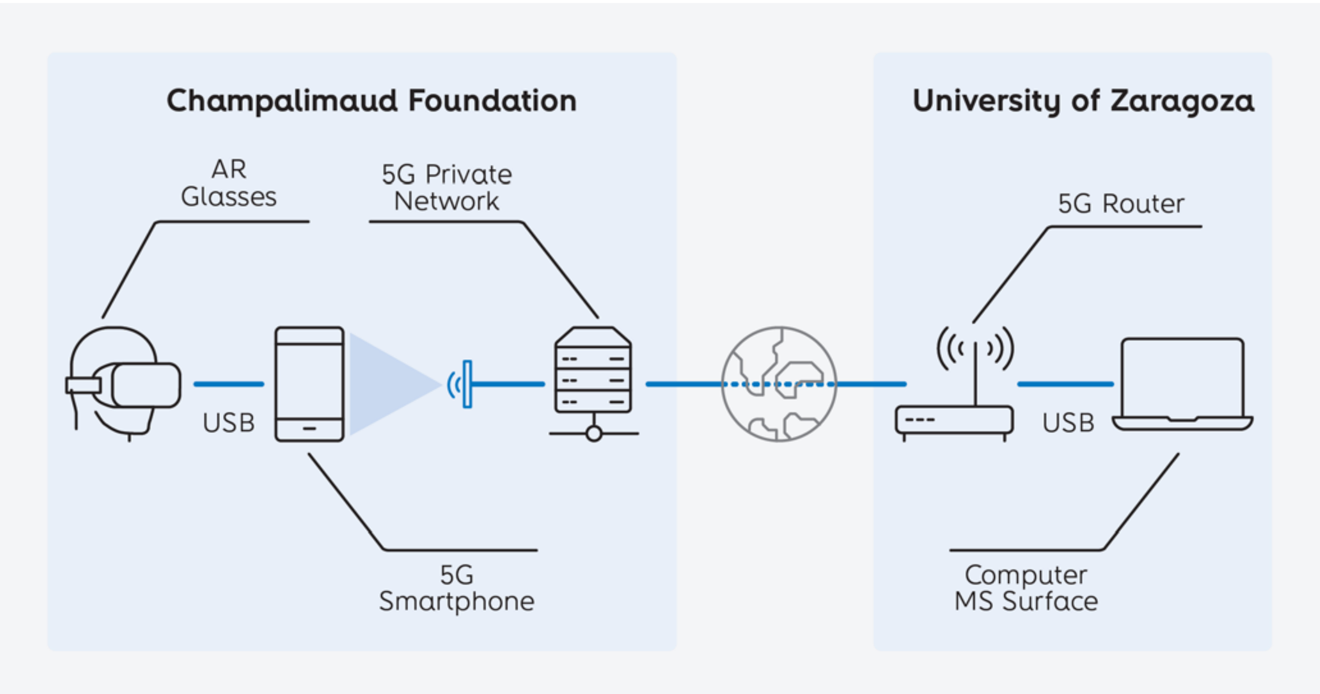

Figure 7 – End-to-end diagram used to setup the demo

Altice Labs' 5G RAN in the context of NPN

Altice Labs' 5G solution for private 5G incorporates all the components required to deploy an end-to-end 5G network, supporting the creation of Standalone Non-Public Networks (NPN) for different verticals, boosted by industry 4.0 and digital transformation movements. It includes the radio access network (RAN) radio units (RU), the RAN software components (Centralized Unit – CU and Distributed Unit – DU), the 5G Core, the required Element Management System (EMS), and hardware servers. It is also capable of integrating non-5G capable terminals via Altice Labs' developed gateways. This can be delivered in greenfield or brownfield environments. Altice Labs can also provide the networking solution, at all network sections, for instance, at the fronthaul, between RU and DU.

The RAN component is an innovative solution developed under the Open RAN [21] concept, designed to achieve the main goals and the efficiency of the 5G networks. Based on specifications from 3GPP and O-RAN architecture, this solution can also be used to extend the operator's networks. It introduces the functional splitting concept to meet customers' new demands that require increasingly higher capacity and connectivity without putting aside cost and efficiency. With it, we can easily scale up and share the various resources, depending on the network demand, and minimize the impact on cell site locations. Altice Labs' solution is flexible, providing the following splits and easily adapting to different deployment scenarios, as shown in **Figure 8**:

- Option 0: Core Network and CU
- Option 2: CU and DU
- Option 7.2x: RU and DU

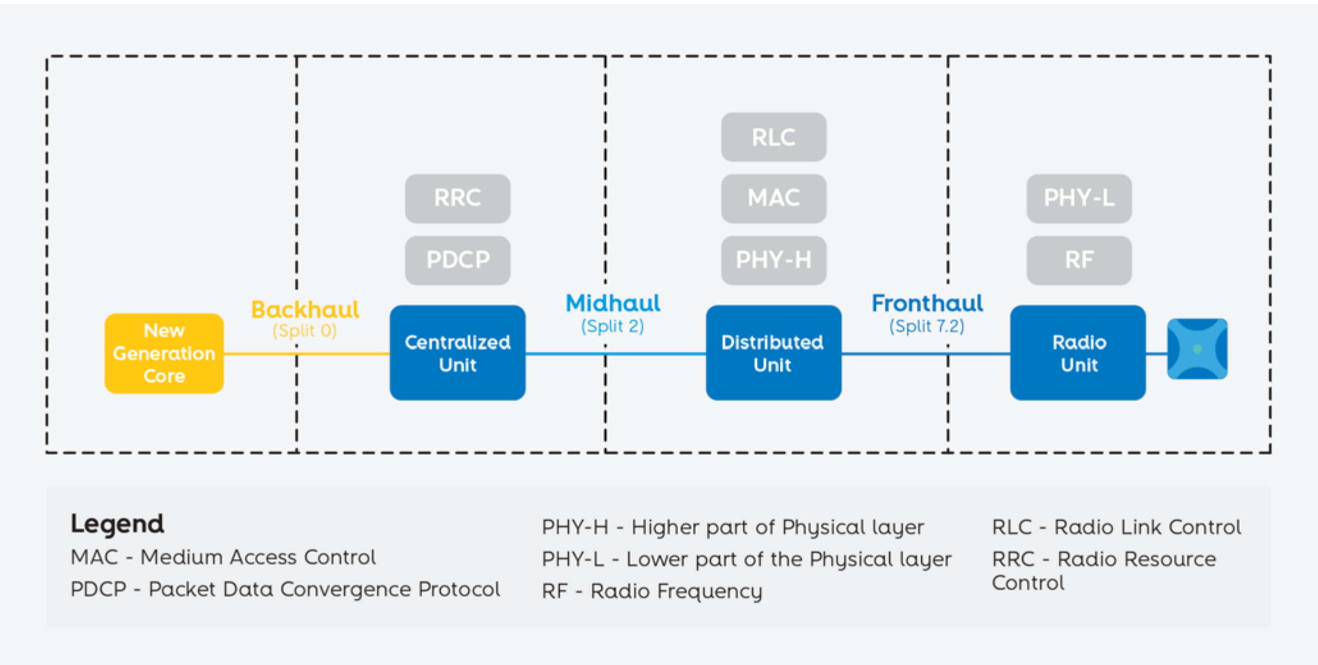

Figure 8 – Splitting points and functional components of Altice Labs' 5G solution

Healthcare environments, where fixed and mobile metal objects are common, but network reliability and predictability are mandatory under all conditions, pose challenges to radio coverage, requiring the densification of antennas. The 7.2x splitting adoption is particularly relevant for SNPN since it minimizes impact and requirements on network radios' placement, indoor and outdoor. Following this approach, radio units are small, requiring energy and a fibber connection.

Altice Labs have been experimenting and proving the integration of some 5G core solutions with its RAN, from open source and vendors. Priority is being given to slicing and QoS capabilities, as well as to easy configuration, operation, and monitoring.

Conclusion remarks

This text described the technological merging of private 5G, edge computing, and AR for an e-health application for remote cooperation between surgeons. AR is an immersive technology that transfers digital data to augmented real-world surroundings to enhance user reality. Applied to the healthcare ecosystem, AR with 5G edge computing will escalate the current standard to high fidelity, to effectively improve performance time, satisfaction, and confidence in post-graduation surgical metaverse education and training.

To achieve an efficient and widespread adoption of the involved technologies, healthcare providers need to rethink hospital communications architecture capable of reaching high fidelity and accommodate immersive technology in daily clinical practice. Infrastructures and buildings in a hospital environment need to follow very strict standards and requirements. Technology deployment also requires a reorganization of the hospital infrastructure.

For an integrated hospital, with wireless devices and technological systems that provide accurate and timely monitoring of environments, supplies, materials, and patients, it is necessary to expand storage and sharing capacity, and have an excellent network to minimize interference and obstacles as much as possible. For advanced connectivity, in addition to expanding the network with the use of fiber optics, IP connections, and wireless connections (WLAN and 5G), it is crucial to rethink healthcare communications architecture for the implementation and proper functioning of these networks. For example, in the present use case, the greatest difficulty in implementing and operating the 5G private network had to do with the walls and windows being thicker and the adopted construction materials, which attenuate the radio signals propagation. In addition, the need for operating rooms to be 'clean rooms' to avoid contamination and cross-infection makes it more complex to lay cables inside the building, when they have not initially foreseen.

These are just two examples, with many more challenges that are needed to be overcome, like the construction of new buildings within the healthcare ecosystem, easing future widespread adoption of advanced communications protocols.

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Acronyms

3D	Three-dimensional
3GPP	Third Generation Partnership Project, a collaboration between groups of telecommunications standards associations
4G	Fourth generation mobile networks
4P	Personalized, preventive, predictive, participatory
5G	Fifth generation mobile networks
6G	Sixth generation mobile networks
AI	Artificial Intelligence
AR	Augmented Reality
B2B	Business-to-Business
B2C	Business-to-Consumer
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
COVID-19	Coronavirus disease 2019
CU	Centralized Unit
DU	Distributed Unit
EC	Edge Computing
EMS	Element Management System
GDP	Gross Domestic Product
IoT	Internet of Things
IP	Internet Protocol
MAR	Mobile Augmented Reality
MEC	Multi-access Edge Computing
ML	Machine Learning
MU-MIMO	Multi-user Multiple-input and Multiple-output
NPN	Non-Public Networks
NTN	Non-Terrestrial Network
OPEX	Operational Expenditures
O-RAN	Open RAN
PLMN	Public Land Mobile Network

QoS	Quality of Service
RAN	Radio Access Network
RRC	Radio Resource Control
RTT	Round-Trip Time
RU	Radio Unit
SNPN	Standalone NPN
URLLC	Ultra-Reliable Low-Latency Communication
URLLC	Ultra Reliable and Low Latency Communications
US	United States
USB	Universal Serial Bus
VR	Virtual Reality
WLAN	Wireless LAN

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