altice labs

# InnovAction

#6 | 2021

"The people who are crazy enough to think they can change the world are the ones who do."

- *Steve Jobs*

# InnovAction

#6 | 2021


993.28
49.65
292.76
206.36


# Striving for a sustainable digital world!

In this fast-changing world, the lifestyle, the way we learn, work, and live together has been shaken by successive challenges that make us deeply question about what the future holds and what can we do to make it more livable, safer, more sustainable in the long run.

Being sustainability the capacity of one generation to fulfill its needs without compromising the fulfillment of the future generations' needs, it involves more than just environmental efforts. Although crucial, environmental-centered strategies are only one helix from a triple helix where societal and economic concerns and practices can't fail to propel the right core strategy towards sustainable growth.

Totally aligned with 'these concerns' and with the best examples we already see cross-industries, Altice Labs is exploring the multiple capabilities behind its digital solutions and connectivity technologies to boost our contribution to tackling carbon emissions by developing more efficient and environmental-conscious hardware while allowing connectivity to reach even more remote locations, connecting people in a sustainable digital world.

In its 6th edition, InnovAction, published by Altice Labs as a technological magazine, highlights the specialized knowledge and best practices we strongly believe will fortify Altice Group's responsible mission, whilst stimulate our Customers and Partners' contribution to a shared value and net-zero emissions economy.

I hope you enjoy reading it, as much as we enjoyed writing it!

**Alcino Lavrador**
*General Manager of Altice Labs*


# Editorial note

Under the topic "Striving for a sustainable digital world", the new edition of InnovAction will shed some light on how technology and connectivity may help reduce the harmful impact that industries have on our planet, namely the global climate and (un)sustainability-related ones.

By aligning business strategy with global actions aimed to reduce our climate footprint and digital social gaps, industries will not only streamline their processes and focus their operations towards (near) net-zero emissions and a sustainable economy but also will help their customers and partners to achieve the same through the products and services they provide them, enhancing a shared value chain. In addition, it will help big corporations to build better trust among customers, investors, and partners, as their visible commitment goes beyond profit.

TELCOS are no exception. Since they are one of the main enablers and promoters of digital smart connected technologies, they are the right advocates to accelerate an action plan to achieve a more sustainable future for the forthcoming generations while smoothing the transition to a greener economy and way of living. Moreover, considering TELCOS are key players in the geographies in which they operate, providing connectivity and managing the infrastructures upon which digital commodity services are offered, they have the power to amplify the benefits of connectivity for communities' prosperity once they create conditions for new businesses to appear, for knowledge to be acquired and for services to be accessible.

Aware of this, Altice Labs, the Altice Group headquarters for RDI, has focused its efforts on inclusion and environmental sustainability, believing that it's something stakeholders value and that it will make the difference in the market landscape, setting this innovation-focused laboratory apart from others with lower performance or late in this urgent race to pursue the sustainable development goals (SDG) promoted by United Nations.


Additionally, to (constantly) enhance the value behind its portfolio, driving the company and customers' contribution to the SDG, Altice Labs is working, among others, on several advanced mobile technologies and applications that foster connectivity infrastructure optimization; network virtualization and cloudification; and mobile (private) connectivity efficiency. In the services arena, the company is developing data-enabled operational tools focused on helping businesses to reduce churn, tune their campaign and market actions, and digitalize their non-core services, always aiming for business and resources efficiencies and rationalization. Finally, on the wellbeing layer and although not new in Altice Labs' portfolio, the company is updating its smart platforms to integrate more and more digital trends and capabilities, believing it can contribute to a net-zero economy while digitally improving the lives of those who use them.

Wrapping up, every player in every sector needs to do its part to tackle this enormous challenge that our planet is already facing. TELCOS, however, are in a unique position to boost a winning solution over smart technologies and applications that will support, on the one hand, the economy decarbonization and mitigate climate change, while on the other hand will leverage behavioral change towards more sustainable ones. (Smart) Cities, (smart) buildings, (smart) living, (smart) agriculture, (smart) industry are some examples of areas that can directly benefit from the power of the connectivity, using connected sensors, and from the capacity of the technologies and solutions developed by Altice Labs to potentiate their environmental and market performance, increasing and promoting sustainable holistic practices. Welcome to the sixth edition of InnovAction!

**Ana Patrícia Monteiro**
ana-p-fonseca@alticelabs.com

# Contents

# 01 Connecting a sustainable digital world

**Fausto de Carvalho, Altice Labs**
cfausto@alticelabs.com

**Filipe Cabral Pinto, Altice Labs**
filipe-c-pinto@alticelabs.com

It is undeniable, technology boosts the digital capabilities of cities and countries. Supported by ubiquitous connectivity, the digitalization of the cities' services, management and infrastructures is an integral part of building an economy for sustainability, where IoT, big data, and artificial intelligence tools will facilitate the inventive capacity, fostering the innovation of services and applications to support the development of Europe as a climate-neutral continent.

## Keywords

Sustainability; Connectivity; Digitalization; SDG; Green Deal

Year after year, the rapid urbanization associated with industrialization processes generated imbalances and leave a huge ecological footprint in our planet that urges to reverse. Some examples:

- Social asymmetries have become more evident;
- Intensive food production doesn't respect the natural cycles and creates tones of waste;
- The massive mobility of goods and people deeply increases traffic jams and air pollution.

Moreover, despite the increasing public awareness and a considerable amount of ongoing worldwide initiatives, the atmospheric temperature and sea-level rise, glaciers are shrinking, forests are being devastated and the oceans, as well as fresh water sources, such as rivers and lakes, are becoming more polluted! Scientists agree that humankind is facing a climate emergency [1], calling for immediate action to preserve Earth and slashing the amount of carbon dioxide in the atmosphere so that extreme heat, storms, wildfires, and ice melt do not become a reckless routine. Climate change is close to becoming irreversible, and the global impact of such change needs to be addressed by everyone with joint and solid resolutions.

# Towards a sustainable future

## Sustainable development goals

To do so and build a better and more sustainable future for all, the United Nations (UN) promoted a universal call for action in 2015, creating 17 sustainable development goals (SDG) to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere, by 2030 [2] – see **Figure 1**.

*"The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and*


**FIGURE 1** – Sustainable development goals [2]

*into the future. At its heart are the 17 Sustainable Development Goals (SDG), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.”* [2]

## European Green Deal

Totally aligned with the SDG, the European Green Deal (see **Figure 2**) was launched by the European Commission in December 2019 and adopted by the European Parliament as the European Union (EU) Climate Law on 24 June 2021. The target is to reduce net greenhouse gas emissions by at least 55% by 2030, aiming


**FIGURE 2** – The European Green Deal [3]

to become the first climate-neutral continent by 2050. The ambition is to position Europe as a global leader against climate change and environmental degradation, assuming the need to transform its economy towards a sustainable future and the need for involvement and commitment of the public and stakeholders [3].

The Green Deal will mainly affect the existing way of life in an urban context since more than half of the world's population lives in cities, which "*account for about 70 per cent of global carbon emissions and over 60 per cent of resource use*" [4]. In fact, the usage of energy has always been significant in society's development and has become crucial in the way we live today. In their oil, coal, or natural gas variants, fossil fuels have been used in energy production. In the combustion process of these natural resources, many pollutants are released into the atmosphere, emphasizing $CO_2$, favoring the greenhouse effect and consequent global warming. Therefore, it is not surprising that the Green Deal has highlighted the construction of an economy for sustainability, not tied to resource usage [5], resorting to a society compromised with preserving the environment.

# Sustainability-digitalization convergence

Sustainability is perceived as a moral and ethical imperative, and public and private administrations are being scrutinized for operating and doing business in ways that contribute positively to the SDG. Corporate social responsibility, for example, is a self-regulating business strategy that guides companies to be socially accountable to themselves, their stakeholders, and the public.

In fact, consumers prioritize sustainability in their decision-making and are more likely to interact with companies that incorporate the SDG into their business strategy [6], that are more conscious and act to reduce their impact on several aspects of society, specially the societal and environmental ones (see **Figure 3**). "*To fully meet their social responsibility, companies "should have in place a process to integrate social, environmental, ethical, human rights and consumer concerns into their business operations and core strategy in close collaboration with their stakeholders, with the aim of maximising the creation of shared value for their owners/shareholders and civil society at large and identifying, preventing and mitigating possible adverse impacts.*" [7]


**FIGURE 3** – Corporate social responsibility main areas of concern

Sustainability also means pioneering innovative technology to optimize resources effectively in the most demanding contexts of fast and reliable digital communications. *"Smart sustainable cities need a telecommunication infrastructure that is stable, secure, reliable and interoperable to support an enormous volume of ICT-based applications and services."* [8]

It is undeniable, technology boosts the digital capabilities of cities and countries. Supported by ubiquitous connectivity, the digitalization of the cities' services, management and infrastructures is an integral part of building an economy for sustainability, where IoT, the generation of big data, the elasticity of cloud resources, and artificial intelligence tools will facilitate the inventive capacity, fostering the innovation of services and applications to support the development of Europe as a climate-neutral continent and the achieving of the Green Deal goals. *"Governments and municipalities can use ICT and other technologies to build smarter and more sustainable cities for their citizens. A smart sustainable city is an innovative city that uses ICT to improve quality of life, the efficiency of urban operations and services and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental and cultural aspects."* [8]

## Altice Labs' commitment

Altice Labs has a long-standing position of solid commitment to sustainability, raising the environmental awareness of employees, suppliers, and partners to act locally to address climate change:

- Green mobility is encouraged through bicycles offered to employees for ecological travel;
- The separation and proper routing of waste, both at office and production activities, is carried out;
- Water consumption and gardens watering is rationalized;
- LED has entirely replaced incandescent lamps to reduce energy consumption.
- Altice Labs' headquarters have been remodeled to optimize energy use while ensuring comfort.

Altice Labs' portfolio has been evolving to support sustainability globally. It includes fully integrated operations support systems products to support multi-technology and multi-supplier environments and enable mobile, fixed, and converged business operators. It provides edge-based solutions to place intelligence close to where it is needed and a cloud-based data management platform with visualization and analytics tools to foster the digital transition in cities, industry, and agro-environments. It also offers a differentiated portfolio of applications resorting to artificial intelligence and machine learning techniques covering virtual assistants, interactive TV, personal advertisement, and well-being, promoting a digital-based enhanced quality of life.

More recently, Altice Labs announced a significant innovation for fiber optic networks, doubling the deployed capacity and allowing it to serve twice as many customers as with current technology – see **Figure 4**. Simply by changing the electro-optical connector where the fiber is connected to the central equipment, the company made it possible to maintain compatibility with current routers without impacting the equipment people have at home.

**FIGURE 4** – Altice Labs' dual SFP electro-optical connector [9]

The existing electro-optical connectors are single small factor pluggable (SFP), the point from where the optical fiber comes out and then split 32, 64, or 128 times reaching people's homes. Altice Labs developed a dual SFP, which allows two optical fibers to be connected on the same port of the central equipment, doubling the number of customers connected by fiber just by changing this interface [9].

Altice Labs' technology is being used daily by over 250 million people communicating worldwide. Hence our commitment to this great opportunity for deep engagement with our society's ongoing sustainable digital transformation, contributing to the transition to a green and lasting digital economy.

# Final thoughts

Sustainability and digitalization are definitely two of the most powerful trends influencing companies' business practices and political agendas. The sustainability-digitalization convergence is, in fact, the foundation of many smart city initiatives, with governments and technology vendors collaborating in the exploration of new ways to improve sustainable living conditions and reduce the urbanization footprint. More efficient data-driven infrastructures with advanced communications relying on sophisticated networks and sensors are being developed, focusing on innovative solutions for several verticals, such as transportation, utilities, health, entertainment, public services, industry and agriculture.

# References


**[1]** Scientific American, "We Are Living in a Climate Emergency, and We're Going to Say So," 12 April 2021. [Online]. Available: https://www.scientificamerican.com/article/we-are-living-in-a-climate-emergency-and-were-going-to-say-so/

**[2]** United Nations, "Departament of Economic and Social Affairs - Sustainable Development," 2021. [Online]. Available: https://sdgs.un.org/goals

**[3]** European Commission, "A European Green Deal," 2021. [Online]. Available: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

**[4]** United Nations, "Sustainable Development Goals - Sustainable Cities and Communities," United Nations, 2021. [Online]. Available: https://www.un.org/sustainabledevelopment/cities/

**[5]** World Economic Forum, "What you need to know about the European Green Deal - and what comes next," World Economic Forum, 13 July 2021. [Online]. Available: https://www.weforum.org/agenda/2021/07/what-you-need-to-know-about-the-european-green-deal-and-what-comes-next/

**[6]** PwC, "Make it your business: Engaging with the Sustainable Development Goals," PwC, UK, 2015

**[7]** European Comission, "Corporate Social responsability, Responsible Business Conduct, and Business & Human Rights," European Comission, 2019

**[8]** ITU, "Smart sustainable cities," ITU, February 2019. [Online]. Available: https://www.itu.int/en/mediacentre/backgrounders/Pages/smart-sustainable-cities.aspx

**[9]** Altice Labs, "Altice Labs announces a major innovation in fiber optic networks," 22 October 2021. [Online]. Available: https://www.alticelabs.com/blog/altice-labs-announces-a-major-innovation-in-fiber-optic-networks/

# 02 Simple VR for better living

**Telma Mota, Altice Labs**
telma@alticelabs.com

**Fausto de Carvalho, Altice Labs**
cfausto@alticelabs.com

**Hugo Paredes, UTAD & INESC TEC**
hparedes@utad.pt

**Leonel Morgado, Universidade Aberta & INESC TEC**
leonel.morgado@uab.pt

Physical and cognitive rehabilitation based on natural interaction and VR has been on our horizon for several years, and we have been conducting experimentation towards that goal through several exploratory research initiatives.
This article addresses some aspects of the state-of-the-art of VR in healthcare and well-being, with opportunities in the domain of rehabilitation based on natural interaction and VR being analyzed and put in perspective with the SmartAL ecosystem product roadmap.

## Keywords

VR; SmartAL; eHealth; Rehabilitation; Exergames; Cognitive games; Assisted living; Active aging; pHealth

# Introduction

The early adoption of novel, cutting-edge technology is usually led by youngsters. Yet, studies, research, and trials around cheaper and more accessible virtual and mixed reality allow us to clearly identify significant opportunities associated with elderly users, who keenly embrace games and applications for physical and cognitive rehabilitation, fighting social isolation and loneliness by enhancing socialization, and active and healthy aging.

This article addresses some aspects of the state-of-the-art of virtual reality (VR) in healthcare and well-being, analyzing opportunities in the domain of rehabilitation based on natural interaction and VR, considering the SmartAL ecosystem product roadmap.

Furthermore, the exploratory project "VReAbility" being carried on by UTAD/UAb/INESC TEC and Altice Labs is presented, focusing on functional requirements and scenario constraints for affordable deployments.

# VR (et al.) for healthcare

In recent years, several studies and projects have demonstrated promising results using video games to address well-being aspects such as increased physical activity and mobility, better socialization and positivity, improved cognitive functioning, and attenuated deterioration with normal aging or in the context of rehabilitation and specific neurodegenerative conditions [1]. Several successful apps are available in the market to allow ad hoc regular cognitive workouts or tracking fitness activity while competing with friends, matching their achievements and progress. Exergames are video games that are also a form of exercise, relying on technology that tracks body movement or reaction. They have been around for more than two decades, going back to "Dance Dance Revolution" (**Figure 1**, **left**), one of the first major successes in the area, which sold over three million copies when ported from the original arcade to PlayStation console in 1998. The popularity of the Nintendo exergames hardware Wii Fit (**Figure 1**, **right**) led to it start being successfully used in multiple hospital "Wiihab" scenarios, such as post-stroke rehabilitation programs and Parkison's disease therapies [2].

Technology has been advancing quickly, with more powerful, affordable, and lightweight devices and, likewise, the potential of applying extended reality (XR) to clinical procedures for wide populations increasing significantly. Researchers have been exploring the potential of using motion capture and VR to address musculoskeletal impairments due to multiple disorders and diseases, or aging [4]. Furthermore, VR is quite promising in the area of physical rehabilitation because it presents patients with an immersive approach. This approach leverages challenges and narratives for context and entertaining to accomplish the precise goals of tedious treatments and protocols addressing aspects such as postural stability and joint mobility, e.g., after surgical procedures, often with the flexibility and comfort of being performed remotely, at home [5]. Recent reviews of VR rehabilitation systems provide evidence of patient enjoyment and willingness to participate in care plans that incorporate VR [6]. Along with the natural interaction based on motion capture, the embodiment is a key aspect of VR efficacy for such applications because it makes the user feel as actually being part of the screen: the avatar, which is the graphical representation of the user, becomes a natural extension of its human body, and the virtual interaction is perceived as real, thus more engaging [7].

Traumatic brain injury (TBI) is a clinical condition that causes attention, memory, affectivity, behavior, planning, and executive dysfunctions, with a significant impact on the quality of life of the patient and family. Cognitive and motor rehabilitation programs are essential for the clinical recovery of TBI patients, improving


**FIGURE 1** – Dance Dance Revolution (left) (AP Photo/Robert F. Bukaty) and Nintendo Wii Fit at the 2009 Gaming World Moscow event (right) [3]

functional outcomes and the quality of life. Various researches have shown that VR has the potential to provide an effective assessment and rehabilitation tool for the treatment of cognitive and behavioral impairment on TBI patients during the different phases of their rehabilitation, creating a positive, motivating, and enjoyable learning experience [8]. VR and augmented reality (AR) are also being used with success in mental healthcare, addressing conditions such as addictions, phobias, and post-traumatic stress disorders, using exposure therapies based on immersive serious gaming and physiological computing (e.g., electroencephalogram headbands).

Many combinations of VR/AR/XR technologies [9] are already common in e-Health and active aging current practices, involving a variety of devices, such as console peripherals, head-mounted displays, wearables, cameras, and sensors, used in multiple scenarios for informal well-being as well as for formal therapies.

## SmartAL - smart assisted living

The need to encourage cognitive and physical activity, empowering people by providing autonomy to conduct their daily activities with minimum external help, yet with confidence by the nearness of professionals and family, led Altice Labs to introduce SmartAL, a telemonitoring and teleconsultation environment where patients, relatives, and caregivers may follow the status of a user/senior in real-time, keeping track of daily health and well-being tasks, using a web, tablet, smartphone, or TV interface [10].

As discussed in the previous section, regular ad hoc use of affordable exergames or fitness apps is effective for staying active. Still, it falls short whenever it involves particular healthcare conditions, which require professional guidance or monitoring the adherence to rehabilitation plans, traditionally associated with lengthy, expensive programs and dedicated facilities. SmartAL approach may be used to extend those plans and professional tracking to the comfort and flexibility of patients staying home (**Figure 2**).

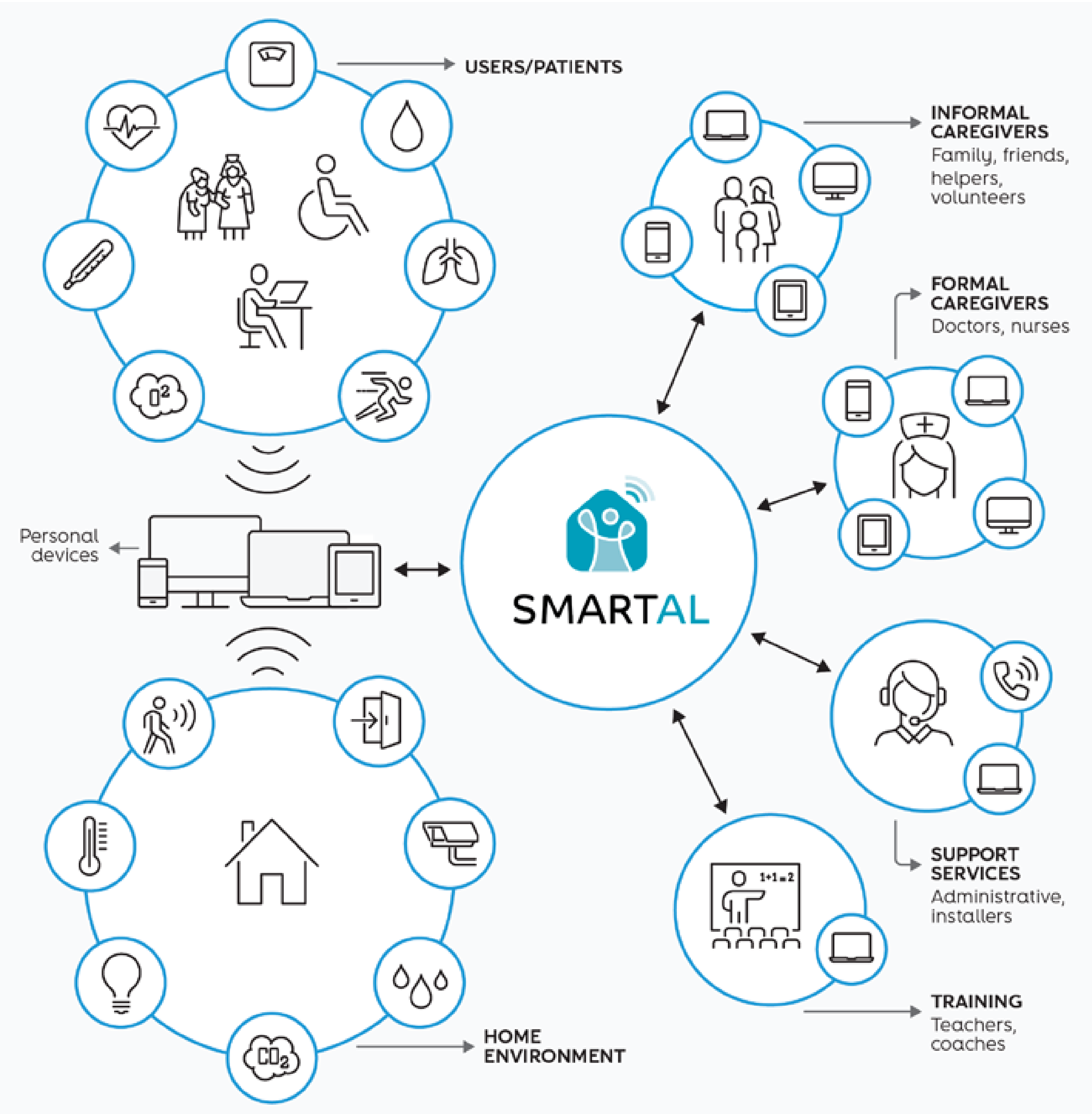


**FIGURE 2** – SmartAL ecosystem

The core functionality of SmartAL consists of collecting information from clinical (e.g., oximeter, thermometer) and non-clinical devices (e.g., personal band, smartwatches) and depicting it to the user. The collected values are matched against thresholds previously configured by healthcare professionals and, when beyond limits, notifications may be sent to both patients and caregivers. Besides telemonitoring of vital signs and teleconsultation, SmartAL also allows simple or medical questionnaires to assess the patient's well-being status, and videos to assist the user in the clinical equipment use or to provide guidance and coaching.

This set of tools provides the necessary services to older people and empowers them with the autonomy to deal with their e-Health activities without the need for constant assistance at home or countless visits in person to the health units. In this context, the key concept for conducting and supporting patients' daily life is the task. Caregivers may schedule tasks and plans (i.e., groups of tasks) to keep track of the users' daily activities. There are predefined types of tasks such as "collect clinical measurements", "take medication", or "perform a teleconsultation". There is also an open type that allows professionals to add new activities on the fly (e.g., "take a five-minute walk", "drink a glass of water every hour"). After defining a task, it is possible to associate it with one or more patients and personalize it by specifying the schedule and who should be notified of the task accomplishment.

## Bridging the gap: VReAbility

Physical and cognitive rehabilitation based on natural interaction and VR has been on our horizon for several years, and we have been conducting experimentation towards that goal through several exploratory research initiatives. With projects such as Online Gym, Move4Health, InMerse, and ARani, we teamed with academia to test concepts and technological aspects, validating the use of low-cost devices for multi-user shared VR-based rehabilitation purposes [11][12]. Furthermore, in the context of the submission of UpperCare and VR2Care proposals to H2020 calls, a panel of specialists with solid expertise on various aspects of the ecosystem was brought together, and we had the opportunity to reach important insights on how to advance the state-of-the-art in this domain, and address our target market [13].

Our vision of bringing VR for physical/cognitive rehabilitation and active aging to the SmartAL roadmap is centered on the need to keep the current operational model in place by creating additional engagement incentives and integrating those functionalities with the already existing mechanisms. This integration would allow personal progress feedback and professional coaching, supervision, and monitoring of adherence to prescribed VR-based tasks and plans, as well as the possibility of automating the platform generation of notifications when certain conditions are met or inferred. Moreover, we are aiming for a very simple and low-cost approach without the need for sophisticated equipment, avoiding driving users and customers away due to increased cost and complexity. Besides the typical one-to-one patient-therapist or the lonely patient-app scenarios, we also want to achieve an architecture open to multi-user shared VR, addressing the important socialization aspects of active aging.

In the scope of ongoing R&D activities for progressing SmartAL, in 2020, we started VReAbility exploratory project with INESC TEC, involving researchers from UTAD and UAb, with the objective of building a prototype to test novel options for motion capture and natural interaction, as well as an architecture for rehabilitation scenarios based on simple VR.

Nowadays, it makes sense to place most of the processing in the cloud. Besides keeping the user-end simple and cheaper, which is an important requirement for this type of service, it also provides easier lifecycle management, including the flexibility of incremental features, for example, the future addition of coaching and monitoring based on artificial intelligence (AI). Moreover,

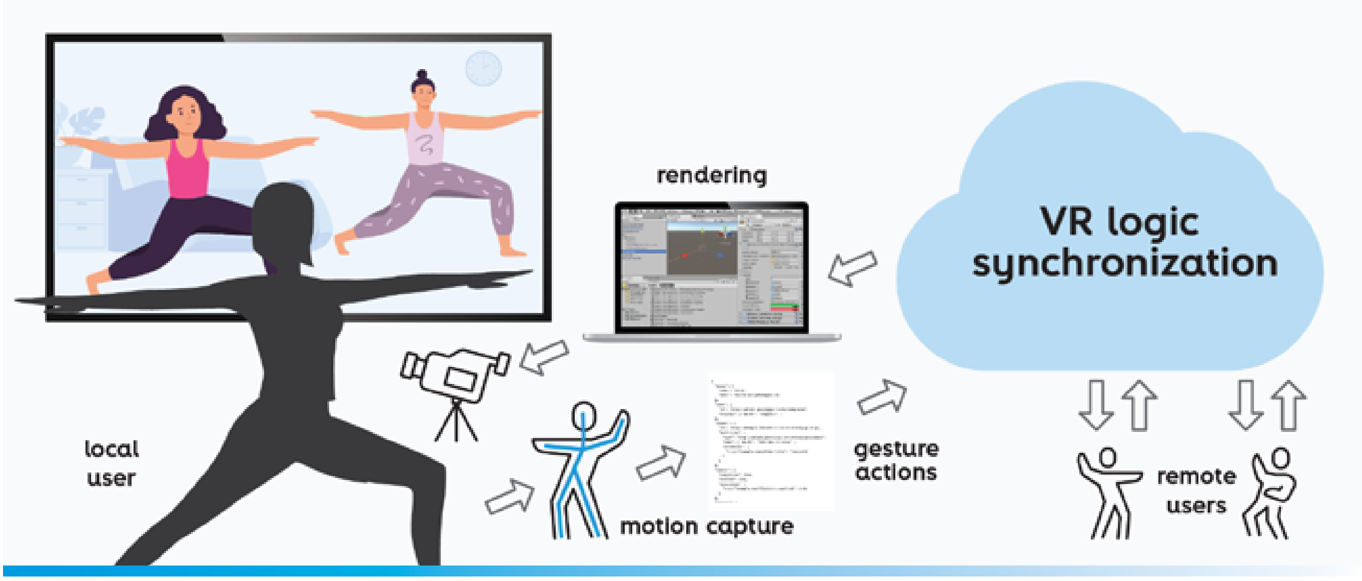


**FIGURE 3** – VReAbility functional architecture

a multi-user scenario requires motion capture streams from multiple users to be mixed, in a single central place, into a common synchronized VR scene.

State-of-the-art software libraries are currently widely available to allow real-time tracking of body keypoints and pose estimation with moderate computational requirements. As so, we used a regular wide-angle webcam instead of relying on specific devices to take care of motion capture (e.g., Microsoft Kinect), as we did in previous projects. This camera option matches the need of having a peripheral to anchor the required functionality at the user target scenario: a small computer (e.g., Raspberry Pi) placed near the TV, hosting the motion capture camera, and feeding the TV with the live VR scene arriving from cloud processing. **Figure 3** depicts VReAbility functional architecture.

After researching and experimenting with several approaches and libraries, VReAbility created a prototype system including the following modules, aligned with the presented architecture:

- Motion capture – whole-body 3D poses are continually estimated, based on OpenPose [14] detection of user body, hands, and facial skeleton keypoints on images captured by the webcam;
- Gestures and actions – the raw stream of poses is matched against a set of rules and processed to recognize relevant gestures that are organized into an experience API (xAPI) [15] sequence of user actions and queued upstream;
- VR logic – the application scenario is a set of VR scenes based on the Unity game engine [16], with an avatar mirroring the user poses. The detected actions are mapped into the scene/game interaction logic so that the user may attempt to achieve the proposed challenges and goals by moving in front of the webcam. Multi-user functionality can be addressed by having a different avatar for each user, with their movement queued as distinct xAPI streams, combined and synchronized into a common VR scene presented to everyone;
- Rendering – the interactive VR scene is shown to the user as a live (TV) video feed. This functionality may be cloud-based, e.g., if computational resources on the target device are limited.

A simple single-user cognitive exergame was developed to test the initial prototype system and explore several aspects of the integration with SmartAL. "Battle Motion Chef" is a multi-level progressive cooking challenge. The player must move sideways and raise the arm to pick the correct ingredients among the random falling ones and place them inside the pot to complete each recipe (**Figure 4**). This game, and other similar ones, may be considered VR hyper-casual games, a very appealing concept currently only applied to mobile applications [17].

## What's next?

Current health services provisioning is mostly acute illness driven. Still, the focus is adjusting towards the management of chronic diseases, preventive healthcare through a healthy lifestyle and extended independent living promotion, prompted by major factors such as population aging and the digital transformation. This requires a completely new approach for health organizations, placing the patient in the center, developing a continuous process, and shifting the care from a hospital-driven approach to a home-driven or, more generally, a pervasive approach. In this context, the wide adoption of new low-cost and patient-adaptive technologies for remote patient management enables trustful, transparent, and not much intrusive monitoring, harnessing effective pHealth solutions – personal, personalized, predictive, preventive, pervasive, and participatory.

Cognitive and physical rehabilitation based on VR exergames is just a fraction of the broad potential of emerging XR and AI technologies applied to the shifting paradigms of healthcare. Although we know we have just scratched the surface, we firmly believe that we are unlocking a powerful ecosystem around SmartAL that can play a significant role in our aging society. Patients, relatives, and caregivers will be provided with an adequate and balanced set of VR tools to support particular rehabilitation needs and to prevent their occurrence through regular monitored activity to maintain and improve physical and cognitive capabilities, for a better assisted life.

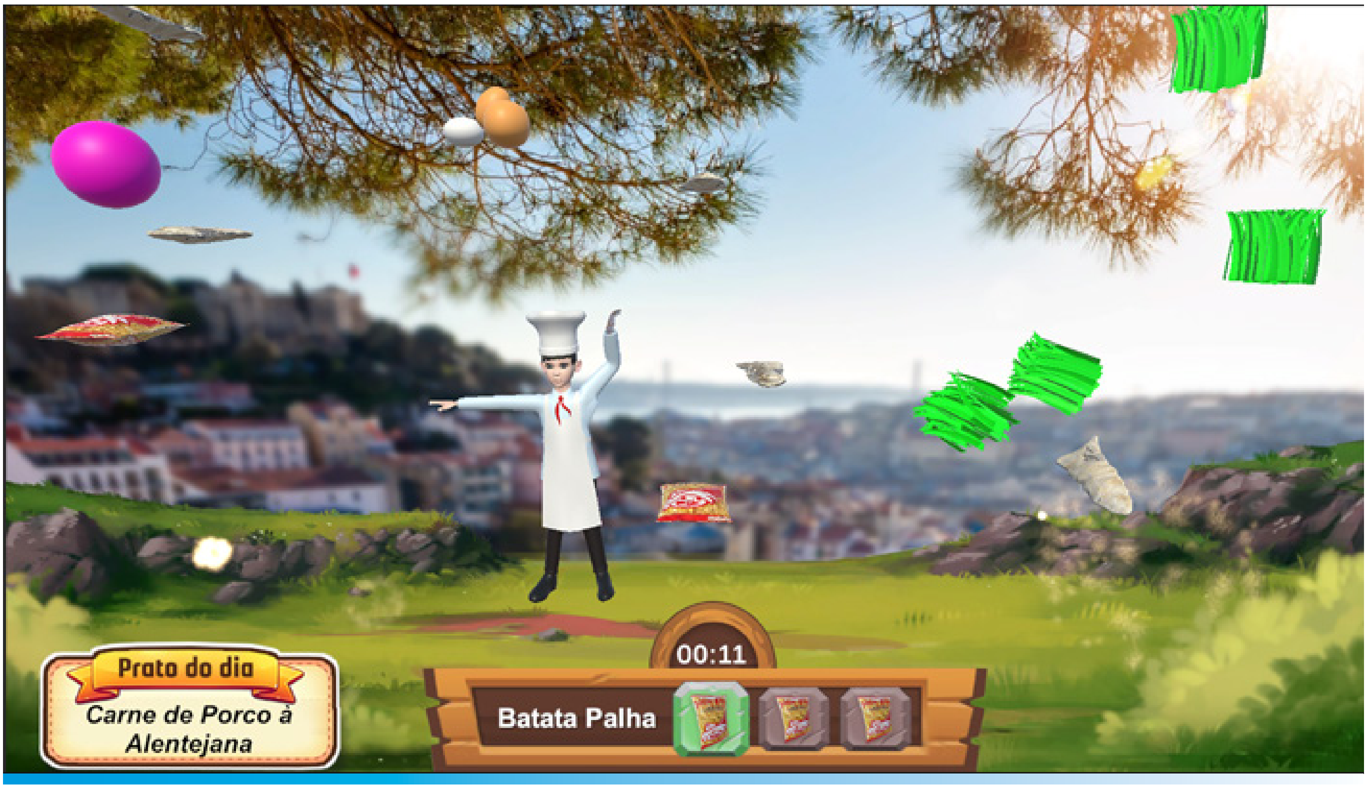


**FIGURE 4** – VReAbility game prototype: Battle Motion Chef

# Acknowledgment

Altice Labs would like to acknowledge the work of the team that created the initial VReAbility prototypes, which includes the authors of this article, and also Fernando Ferreira (UTAD/Altice Labs), Domingos Forno (UTAD), Demetrius Lacet (INESC TEC), Ricardo Nunes (INESC TEC), João Mendonça (Altice Labs), and Ricardo Machado (Altice Labs).

# References

**[1]** F. L. Vázquez, P. Otero, J. A. García-Casal, V. Blanco, Á. J. Torres, and M. Arrojo, "Efficacy of video game-based interventions for active aging. A systematic literature review and meta-analysis," *PLoS One*, vol. 13, no. 12, p. e0208192, Dec. 2018, doi: 10.1371/journal.pone.0208192

**[2]** N. B. Herz, S. H. Mehta, K. D. Sethi, P. Jackson, P. Hall, and J. C. Morgan, "Nintendo Wii rehabilitation ('Wii-hab') provides benefits in Parkinson's disease," *Parkinsonism Relat. Disord.*, vol. 19, no. 11, pp. 1039–1042, Nov. 2013, doi: 10.1016/j.parkreldis.2013.07.014

**[3]** Wikimedia Commons, "File:Wii Fit girl at Igromir 2009 (4082095322).jpg --- Wikimedia Commons{,} the free media repository." 2020. [Online]. Available: https://commons.wikimedia.org/w/index.php?title=File:Wii_Fit_girl_at_Igromir_2009_(4082095322).jpg&oldid=472904329

**[4]** F. Cassola, L. Morgado, F. de Carvalho, H. Paredes, B. Fonseca, and P. Martins, "Online-Gym: A 3D Virtual Gymnasium Using Kinect Interaction," *Procedia Technol.*, vol. 13, no. December, pp. 130–138, 2014, doi: 10.1016/j.protcy.2014.02.017

**[5]** T. Rose, C. S. Nam, and K. B. Chen, "Immersion of virtual reality for rehabilitation - Review," *Appl. Ergon.*, vol. 69, pp. 153–161, May 2018, doi: 10.1016/j.apergo.2018.01.009

**[6]** G. Tao, B. Garrett, T. Taverner, E. Cordingley, and C. Sun, "Immersive virtual reality health games: a narrative review of game design," *J. Neuroeng. Rehabil.*, vol. 18, no. 1, p. 31, Dec. 2021, doi: 10.1186/s12984-020-00801-3

**[7]** K. Kilteni, R. Groten, and M. Slater, "The Sense of Embodiment in Virtual Reality," *Presence Teleoperators Virtual Environ.*, vol. 21, no. 4, pp. 373–387, Nov. 2012, doi: 10.1162/PRES_a_00124

**[8]** M. G. Maggio *et al.*, "Cognitive rehabilitation in patients with traumatic brain injury: A narrative review on the emerging use of virtual reality," *J. Clin. Neurosci.*, vol. 61, pp. 1–4, Mar. 2019, doi: 10.1016/j.jocn.2018.12.020

**[9]** D. Beck, L. Morgado, and P. Shea, "Finding the Gaps about Uses of Immersive Learning Environments: A Survey of Surveys," *JUCS - J. Univers. Comput. Sci.*, vol. 26, no. 8, pp. 1043–1073, Aug. 2020, doi: 10.3897/jucs.2020.055

**[10]** Altice Labs, "SmartAL: Smart Assisted Living," *Altice Labs*, 2020. https://www.alticelabs.com/products/ehealth-smart-assisted-living/

**[11]** F. de Carvalho, V. Orvalho, and L. Morgado, "Motion capture: aplicações e-health e wellbeing," *Saber & Fazer*, pp. 270–275, 2014, [Online]. Available: http://hdl.handle.net/10400.2/4438

**[12]** F. de Carvalho and H. Paredes, "HCI boosted by AI," *InnovAction*, vol. 4, pp. 100–109, 2019, [Online]. Available: https://www.alticelabs.com/wp-content/uploads/2021/07/InnovAction_2019.pdf

**[13]** H. Paredes *et al.*, "UPPERCARE: A community aware environment for post-surgical musculoskeletal recovery of elderly patients," in *2017 IEEE 21st International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, Apr. 2017, pp. 251–256. doi: 10.1109/CSCWD.2017.8066703

**[14]** G. Hidalgo *et al.*, "OpenPose," 2021. https://github.com/CMU-Perceptual-Computing-Lab/openpose

**[15]** Rustici Software, "xAPI.com," 2021. https://xapi.com/

**[16]** Unity Technologies, "Unity," 2021. https://unity.com/

**[17]** Adjust and Unity, "Hyper casual gaming in 2020," *Adjust*, 2020, [Online]. Available: https://www.adjust.com/resources/downloads/hyper-casual-report-2020/?download=%2Fresources%2Fdownloads%2Fhyper-casual-report-2020

# 03 The power of engagement micro-journeys

**Fernando Santiago, Altice Labs**
fernando-m-santiago@alticelabs.com

**José Miguel Freitas, Altice Labs**
jose-m-freitas@alticelabs.com

**Jorge Miguel Sousa, Altice Labs**
jorge-m-sousa@alticelabs.com

Nowadays, the customer interaction performance of many companies and brands is strongly affected by the lack of consistent customer experience across channels, often being siloed, disjointed, and disconnected. The lack of full integration of conventional and new digital channels with applications and business processes often compromises the digitally connected experience of the customers in the relationship with companies and brands.
The article presents the landscape of business communications platforms, some of the most relevant use cases of CPaaS, the opportunities and challenges for CSP in this business space, and an overview of the new Altice Labs' CPaaS solution.

## Keywords

Customer interaction; CpaaS; Multi-channel; Advanced cloud services; Visual Builder tool

# Introduction

In the last two years, cloud business communications platforms have been strongly leveraged by the transformation needs imposed by the COVID-19 pandemic. The outbreak crisis forced organizations to change quickly and take advantage of the available cloud-based solutions to keep the businesses running. Since many of these organizations were unprepared, the transition was not smooth and required them to quickly adapt their existing processes for remote work and online communication and collaboration. In parallel, for many organizations to survive, they had to accelerate the digitization of their customer interactions, operations, and supply-chain workflows. Thanks to the communication solutions already in place and their evolution during the pandemic, the transformation was possible in a short time. Cloud business communication platforms have played a fundamental role in this transformational era and societal change.

Nowadays, the cloud business communications market comprises three main pillars: unified communication as a service (UCaaS), contact center as a service (CCaaS), and communications platform as a service (CPaaS).

- **UCaaS:** provides a comprehensive set of tools, combining voice, video, messaging, conferencing, and collaboration, helping organizations keep their workforce connected and productive, giving a consistent communication experience across channels and devices. Some of the main functions are call forwarding, advanced call routing, call recording, instant messaging, web conferencing, and tools for teams' collaboration. UCaaS is mainly used for internal communication within the enterprise.

- **CCaaS:** is the evolution of the classic on-premises contact center platforms but provided in the form of subscription-based cloud software as a service (SaaS), avoiding the need of the organizations to invest in hardware and platform software licenses and to have infrastructure maintenance costs. Typically, this kind of cloud communication platform is aimed at small and medium businesses (SMB), offering a streamlined onboarding process built, taking scale in mind. This new wave of contact center platforms is designed to allow service representatives and salespeople to easily connect with the customers across multiple channels, providing a set of functionalities to make the agents more productive. Call queuing, routing, and recording, interactive voice response (IVR) menus, voicemail, reporting and analytics, integration connectors with most popular business software (e.g., customer relationship management - CRM, and helpdesk). Bots, natural language processing (NLP), and artificial intelligence (AI)/machine learning technologies, which can improve the attendants' performance and boost customer satisfaction, have also been included in CCaaS solutions. The coherent combination of unified communications and contact center functions helps organizations to be even more customer-centric. A helpdesk agent's ability to easily access an internal expert to obtain rapid answers while engaging with the customer is an example of this value-added integration, which positively impacts the customer experience. UCaaS and CCaaS are full-featured communication package software tools targeted to the organization's users.

- **CPaaS:** offers developers or business technologists a framework to integrate advanced communication capabilities into existing business processes and applications (web sites, mobile apps, and enterprise applications). CPaaS expands the possibilities far beyond UCaaS and CCaaS since it provides the organizations the communication building blocks to drive an integrated and tailored customer experience for a fully digitalized engagement journey. As per Gartner's market definition [1], CPaaS offers application leaders a cloud-based multilayered middleware on which they can develop, run, and distribute communications software. The platform provides API that simplify the integration of communications capabilities (for example, voice, messaging, and video) into any app, service, or business process. CPaaS delivers the means for organizations to infuse advanced communications capabilities into existing workflows through a visual builder tool that enables non-technical users to build the workflows with a user-friendly drag-and-drop graphic approach.

In fact, the no-code or low-code paradigms, such as proposed on CPaaS approach, are gaining momentum in a new age of synergies between IT personnel and non-IT people in highly collaborative agile contexts. The democratization [2] of business processes and applications development, allowing people without coding skills or little experience to participate in the solutions building processes directly, presents promising prospects and empowers organizations to achieve higher productivity, accelerate the time-to-market when launching new products and services, and improve teams' motivation.

This no-code/low-code movement is paving the way in the CPaaS adoption. Visual builders are one of the evolving areas where the vendors focus on improving their tools to attract non-technical people. Additionally, beyond the API (voice, VoIP, video, messaging, chat, and numbering) and visual environments for workflow composition and design, CPaaS stacks are also including additional functionalities, which complement the communication functions, such as authentication, anonymization, payments, sentiment analysis, and task routing.

For customers, CPaaS allows accelerating the transformation towards complete digitalization, enabling the rapid creation and improvement of applications and business processes at lower costs. CPaaS is at the heart of the transformation pathway in an age where organizations need to rethink the customer engagement journey to deliver an even more connected and frictionless customer experience. Building micro-journeys straightforwardly and fully integrated with the existing processes and IT assets of the company, in a coherent omnichannel engagement approach, represents a step ahead in interacting with the customers, wherever they are or whatever terminal and channel they choose to use.

# CPaaS use cases

CPaaS, as mentioned before, has the power to accelerate the digital transformation in a wide variety of industries, including healthcare, education, retail, finance, hospitality, and smart living, to name just a few. There are countless scenarios and use cases that can take advantage of its functionalities, namely:

- **Hospitality:** Hotels can automate and fully digitalize the interaction with their customers. By integrating the existing processes with virtual assistants, hotels can simplify the booking, check-in, and check-out processes. This interaction journey can benefit from other CPaaS core capabilities such as: multi-channel reminders that can be sent during all the phases to improve customer satisfaction and reduce no-shows; two-factor authentication to reinforce interactions' security; advanced AI functions (e.g., sentiment analysis) to improve the interaction efficiency.

- **Retail:** Traditional and online retailers have in CPaaS solutions an excellent opportunity to improve the customer experience, such as in the onboarding and delivery processes, by sending registration contacts validation, order confirmations, shipping information, and real-time delivery updates. However, retailers can go further with CPaaS by recurring to intelligent IVR and virtual assistants in the pre-sales and post-sales, improving the efficiency and providing a 24x7 first line of support and help, avoiding missing any critical contact.

- **e-Government & smart cities:** In recent years, central and local governments have been implementing a new age of e-services to improve citizens' quality of life and get better efficiency of the traditional services. CPaaS is a foundational component, complemented with IoT, AI, and 5G technologies, to deliver innovation and build an innovative ecosystem to address the emerging opportunities in this space. The future of excellent public citizen-centric services will benefit a lot from the CPaaS services.

- **(Contactless) shopping:** The integration of a variety of sensors, cameras, and machine learning technologies, allowing the customers, after a quick check-in using their smartphone, to walk inside the store, picking up items from the shelf and, in the end, walkout from the store without the need to stay in a queue waiting for validation and payment, represents a step ahead in the shopping experience – already being tested by Amazon. In the future, with the massification of this concept, new opportunities will open for CPaaS services providers. The connected real-time omnichannel experience required in this kind of new contactless and cashless stores can enormously benefit from CPaaS services and capabilities embedded in the involved complex automated processes.

In the following sub-sections are explored in more detail two additional practical examples of usage in the healthcare and sales & marketing domains.

## Healthcare: advanced cloud IVR

Due to constraints on the staff dimension, a small dentist clinic decided to use robotic process automation (RPA) to automate patient interactions (see **Figure 1**) to schedule and re-

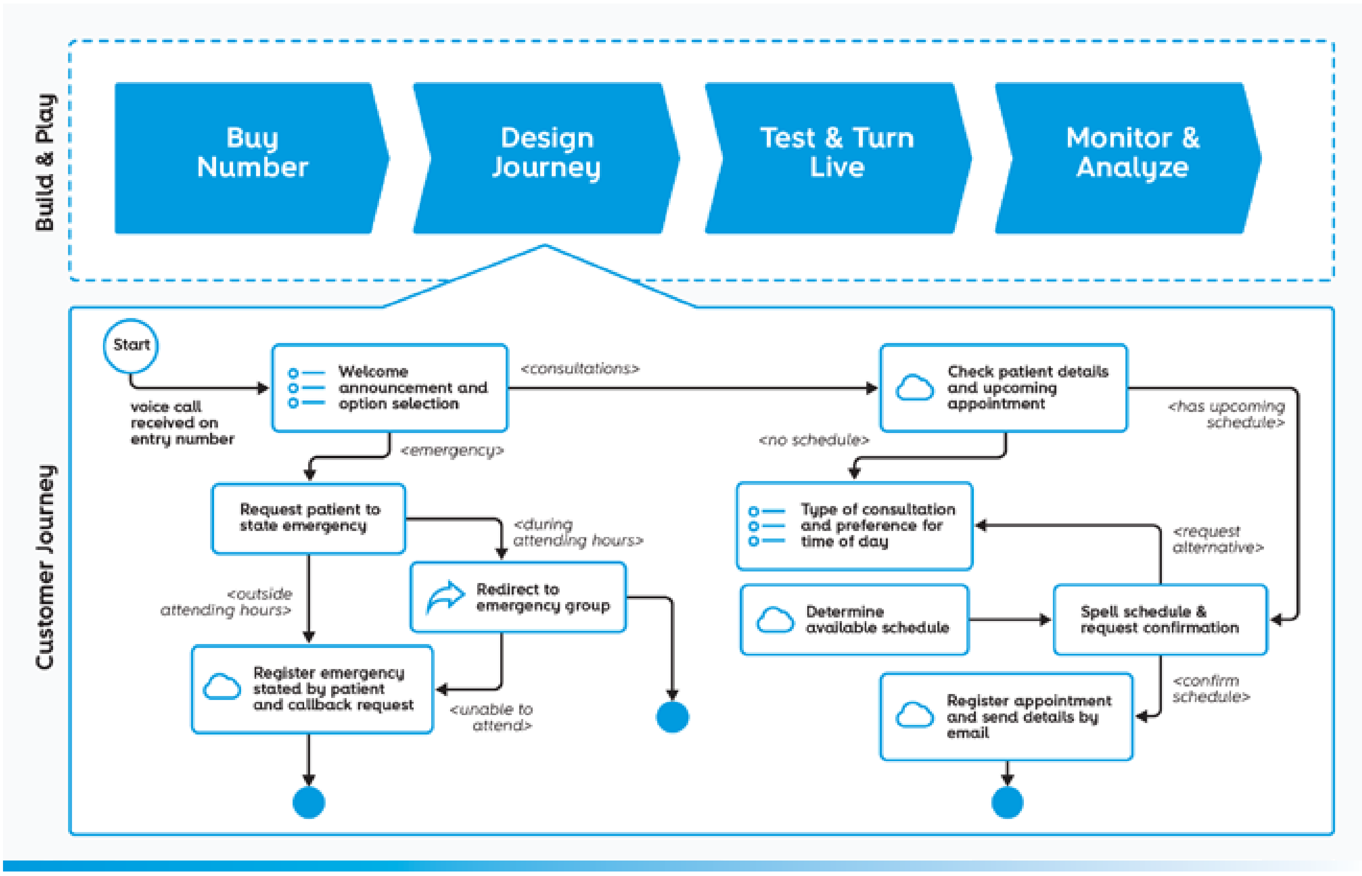


**FIGURE 1** – Healthcare use case

schedule appointments, freeing up the attendants for tasks requiring human reasoning. In this RPA, all incoming phone calls for appointment scheduling are handled by the call flow journey designed through the CPaaS Visual Builder tool that combines the system capabilities to play announcements and IVR to recognize options selection and interface with external functions.

Each journey for a voice channel requires one or more telephone numbers to enable incoming and outgoing calls. The enterprise can select from his free numbers as previously provided or buy new ones directly from the service provider.

The journey begins when a call is received on one of the specified entry numbers. In **Figure 1**, the clinic decided to have both flows for emergency attending and appointment scheduling right at the beginning. An announcement with an IVR presenting the available options enables the selection via dual tone modulated frequency (DTMF) digits input from the caller's phone or voice recognition.

Moreover, the clinic decided that the emergency attending service was only available during a specific period. For calls received outside that period, the patients leave a callback request that triggers a notification for analysis and retrieval when possible. For appointments, the journey interacts with the clinic's schedule system to retrieve scheduled appointments for the calling patient and allow patients to schedule a new appointment or re-schedule to another available slot. As the journey ends, a notification confirming the changes is sent for both patient and the clinic attendant.

## Sales & marketing: automated multi-channel customer interaction

A small and medium business (SMB) company decided to launch a new marketing campaign for some of their products and services to improve sales (see **Figure 2**). In the visual tool of the CPaaS

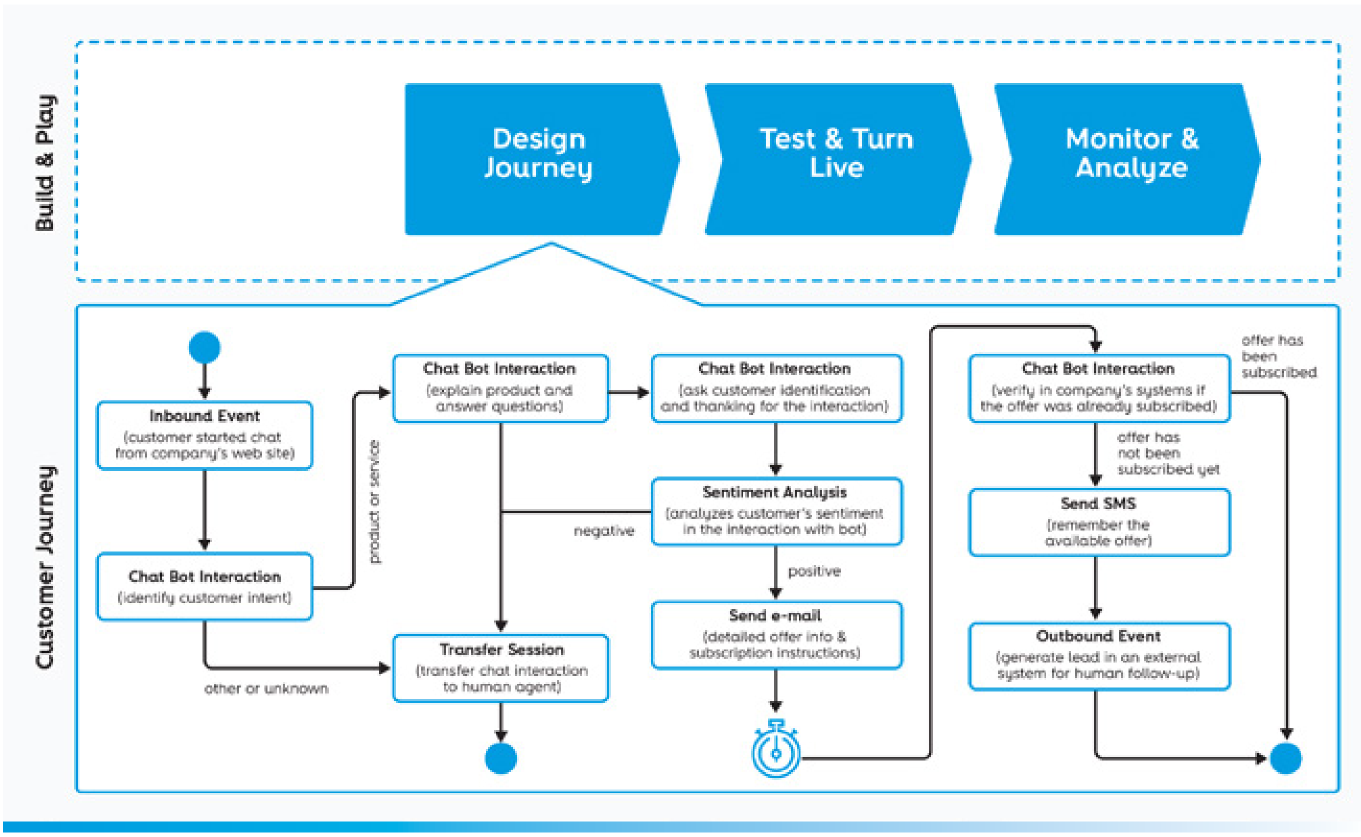


**FIGURE 2** – Sales & marketing use case

Platform, the business team designs the interaction flow for the desired customer micro-journey. The journey begins when a user visits the company's website, being invited to start an online chatbot session. The bot tries to recognize his intent and asks his name to have a more personalized interaction. In case of interest in a product or service, the bot answers the customer's questions. When the customer manifests an interest in additional information during the interaction, the bot asks him to indicate his contact information (e-mail and phone number) for future communications. During the interaction, the sentiment of the customer is being monitored and classified. If it is negative, the session is transferred to a human agent, otherwise an e-mail is sent thanking the customer and giving more detailed information about the product or service. After two days, if the customer does not subscribe to the offer, a reminder SMS is sent.

After designing the interaction journey, the business team must instruct and train the bot to answer the customer's questions. A script file can be uploaded with the customers' most frequent questions and answers to ease and accelerate the training phase. After testing the overall interaction flow, the business team activates the flow to be available online for the customers.

These two use cases illustrate the potential and benefits of integrating real-time communication and AI capabilities in existing processes towards full digital customer interaction services: it increases efficiency and enhances engagement while creating a better customer experience.

# CPaaS and the CSP

CPaaS represents the opportunity for communication service providers (CSP) to increase revenues and strengthen relationships with enterprise customers who want to innovate and accelerate digital transformation. In recent years, the market has been experiencing solid and consistent growth [3] [4], penetrating companies of all dimensions, types, and sectors, driven by the ongoing digital transformation on organizations, which is motivating a "gold rush" among the vendors, given the promising perspectives of revenues.

In an era of everything-as-a-service (XaaS), CSP need to rethink and redefine their offerings to remain competitive in the business communications space. Keeping in mind the transformation changes in place, they should provide a new age of cloud-based services, with embeddable real-time communication capabilities and an orchestration framework, to make it easier to drive innovation in the applications and processes of their enterprise customers, improving stickiness and loyalty (decreasing the churn rate). By implementing their own CPaaS services or partnering with enablement vendors, CSP can gain a competitive advantage and improve profits, competing with global players.

## Altice Labs' CPaaS solution overview

Altice Labs has a vast track record of creating and delivering innovative communication platforms. Regarding business communications platforms, Altice Labs is building a coherent CPaaS stack incorporating some existing platforms of its current portfolio and developing new services to complement the offer – **Figure 3** presents a layered vision of this new stack.

In the following sub-sections, each of the layers are covered in more detail.

### Network layer

Altice Labs' CPaaS platform interfaces with the CSP network via session initiation protocol (SIP) protocol, enhancing the call and SMS treatment capabilities on the CSP numbering plan and enabling SIP-trunk interface scenarios. Enterprises can use their existing numbering or acquire more numbers from the CSP.

Additionally, the platform connects directly over the Internet to other over-the-top (OTT) services/

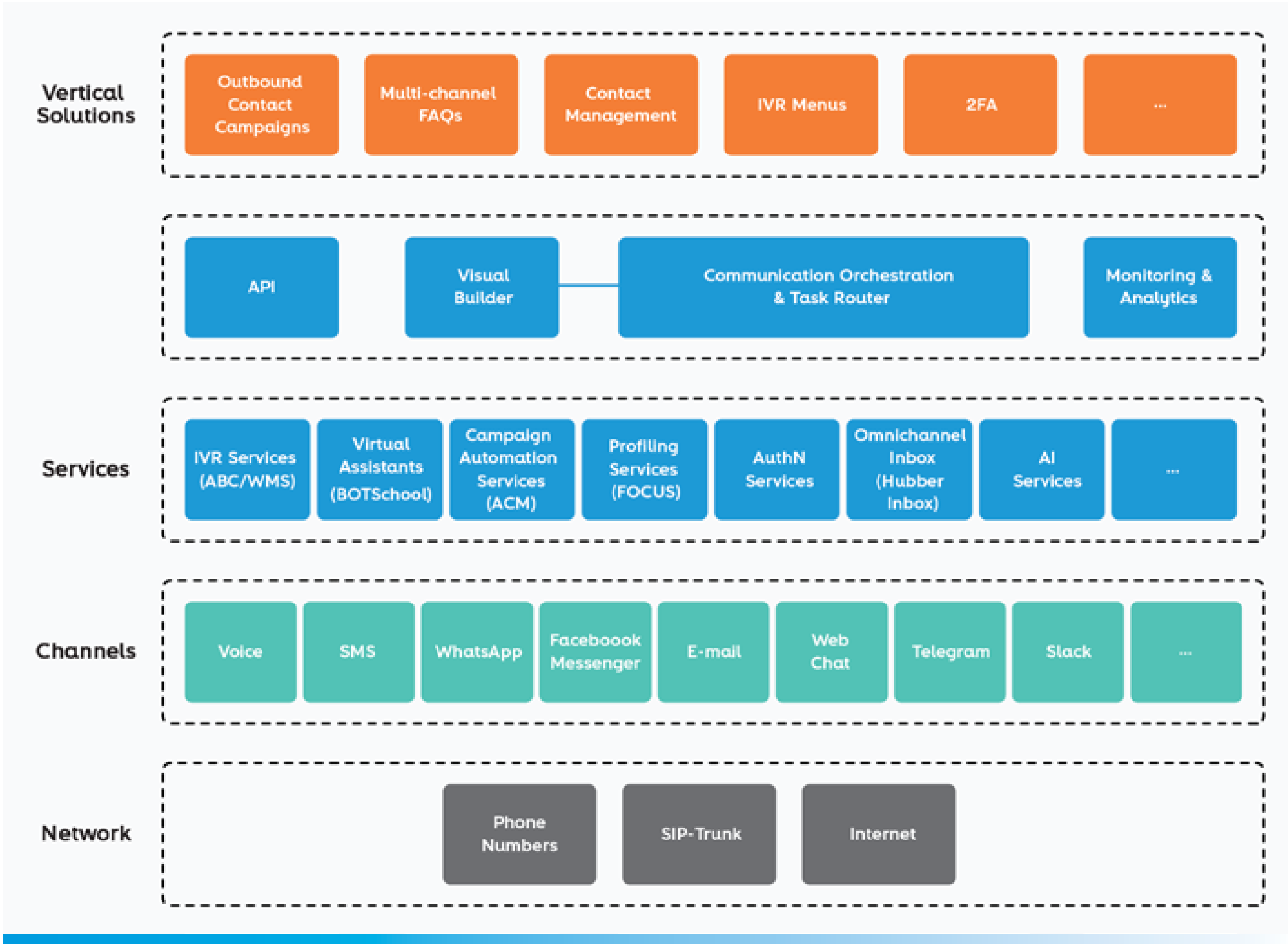


**FIGURE 3** – Altice Labs' CPaaS stack

channels, such as WhatsApp and Facebook Messenger. These types of services might require 3rd party activation.

## Channels layer

The multi-channel architecture of the Altice Labs' CPaaS platform provides the ability to combine multiple indirect and direct communication channels, enabling flexibility on the CSP customers' communication strategy and empowering people to choose the most convenient channel when engaging with companies and brands.

Being this platform built on top of an extensible framework, more channels can be added whenever required by specific use cases and when there is a market demand.

## Services layer

Besides the multi-channel capabilities, the platform integrates various services from the Altice Labs' products portfolio:

- For **voice communication channels**, traditional IVR with input digits recognition and conversational IVR with natural language processing are made available by enhancing those features from Advanced Business Communications (ABC) and Windless Media Server (WMS) products.
- For more **elaborated IVR interactions and virtual assistant services**, it is possible to integrate with the BOTSchool. This low-code virtual assistant cloud solution eases creation and management for any channel, allowing to train conversational

bots capable of natural language understanding, engaging complex interactions with the customers (by voice or messaging) with the capability to interpret intents, make decisions based on context, and even evaluate customer sentiment that can influence the answer.

- **Campaign Automation** is a bundle of real-time multi-channel marketing automation services provided by the Active Campaign Manager (ACM), a suite to create, run, monitor, and optimize multi-channel contextual and personalized marketing campaigns. Campaign automation services can be invoked from the communication flows, for instance, to obtain information about the campaigns available for a specific customer.

- **Customer profiling services** are provided by FOCUS, a profiling system able to collect data from external sources, process, transform and store customer profiles in a unified view. Profiling services can be used to make decisions in the communication flows based on customer data (e.g., user preferences, inferred preferences, services usage insights).

- **Altice Labs' CPaaS Inbox** is an omnichannel solution that aims to provide a centralized deck to enable seamless communication aggregation, customer engagement approaches, unified messaging experience combined with voice and IVR capabilities, removing boundaries between different means of communication channels.

Other transversal services, such as authentication functions and AI services (natural entity recognition, automatic speech recognition, text to speech, optical character recognition, and language detection), are also available for integration within journey configuration.

## Orchestration & interfaces layer

All the interfacing with the platform can be achieved via interfaces and API, ranging from management functions to control functions for services and channel events. It provides the means for CSP and their partners and customers to implement specific solutions for their business processes integrated into their systems.

Altice Labs' CPaaS Visual Builder tool can be used as an alternative to the programmatical approach or as a complement. Customers can design by themselves interaction flows for voice and messaging channels on a user-friendly web application frontend simply by dragging and dropping building blocks and defining the connections and transition conditions between them, requiring only the knowledge of the business case to be supported. Those flows designed on the Visual Builder tool are then interpreted by the communication orchestration and task router component, responsible for managing each flow's life cycle according to the triggered events and the subsequent step conditions.

## Vertical solutions layer

This layer provides a flexible framework to implement a wide range of use cases such as:

- **Outbound contact campaigns** supported in ACM services, virtual assistants and other AI functions (e.g., sentiment analysis);

- **Multi-channel FAQ** by leveraging the conversational bot's ability to recognize intents and provide contextual responses;

- **Inbound and outbound contact management** flows by combining the call distribution capabilities from ABC and WMS components;

- **IVR menus** with the possibility to integrate with bots and external systems;

- **Two-factor authentication** (2FA) scenarios.

Wrapping up, Altice Labs' CPaaS is a comprehensive communication stack, built taking advantage of our experience in business communications platforms. This ecosystem, complemented with new functions, API, and tools, supported in a strong orchestration foundation, provides the ingredients that will empower CSP to offer new services to their business customers.

# Conclusions

Customer habits, needs, and expectations are changing quickly, requiring enterprises the agility and speed to follow the ongoing changes. On top of this, the recent pandemic precipitated many businesses' digital transformation, increasing the demand for omnichannel real-time communication solutions to enable a seamless connected experience between enterprises and their customers. It is also leveraging the growth of cloud-based business communications platforms - UCaaS, CCaaS, and CPaaS, which expands the possibilities far beyond the first two platforms, mainly due to:

- Embeddable communications linked with AI capabilities (e.g., bots, virtual assistants, sentiment analysis) and other advanced services (e.g., authentication, profiling), enabled by CPaaS, empower enterprises to create new or evolve existing applications and processes, improving efficiency and delivering a superior customer-centric experience for better engagement.
- Easy to integrate API and low-code/no-code paradigm tools emerged and became key assets to unlock the power of CPaaS, providing the foundation for programmers and non-technical personnel to access features like the multi-channel communication capacity that in the past was a major challenge with high developing cost.
- The ability to instantly buy a number and quickly create a communication flow with, for instance, IVR menus, call forwarding, call recording or online multi-channel messaging, opens countless opportunities, taking enterprises to a new level of agility in this new digital age. Designing connected customer journeys and joining communications channels with AI services, straightforwardly through a visual builder tool, represents a step ahead to scale up the CPaaS adoption by engaging with non-IT enterprise employees (e.g., business technologists, citizen developers).

CSP need to continue playing a central role in business communications. Despite the threats of OTT players in this area, the telecommunications industry has a new range of opportunities that can be leveraged by their network assets, technological knowledge, and customer base. Having a CPaaS strategy can help operators face this digital transformation, maintaining a competitive advantage over the OTT players.

# References

**[1]** Gartner, “Glossary : Communications Platform as a Service (CPaaS)”, 2021, [online] https://www.gartner.com/en/information-technology/glossary/communications-platform-service-cpaas

**[2]** [2] Amit Zavery, Forbes, “How No-Code And The Democratization Of Application Development Are Helping Businesses”, 2020, [online] https://www.forbes.com/sites/googlecloud/2020/06/25/how-no-code-and-the-democratization-of-application-development-are-helping-businesses/?sh=2c18623c6f98

**[3]** [3] Stephen Sale, Analysys Mason, “The CPaaS market continues to consolidate”, 2021, [online] https://www.analysysmason.com/research/content/articles/cpaas-market-consolidation-rdmv0/

**[4]** [4] Arthur D. Little, “Closing in: The development of CPaaS towards a cohesive market structure”, 2021, [online] https://www.adlittle.com/en/insights/viewpoints/closing-development-cpaas-towards-cohesive-market-structure

# 04 Towards churn prediction on TELCO operators

**Bernardo Duarte, Altice Labs**
bernardo-x-duarte@alticelabs.com

**Ana Mestre, MEO**
ana-m-mestre@telecom.pt

**Ricardo Filipe, Altice Labs**
ricardo-a-filipe@alticelabs.com

**Nuno Pimenta, MEO**
nuno-pimenta@telecom.pt

In a world full of services and with the cost of acquiring a new customer much greater than retaining customers already in the operator, detecting who is about to leave a company proves to be a crucial differentiator factor in TELCO companies. This study clarifies that churn prediction is possible and very feasible through raw datasets and feature engineering.

## Keywords

Churn; Top-up; Machine learning; SHAP; Customer retention

# Introduction

Despite their stable maturity, current telecommunication operators have some herculean challenges in acquiring and retaining clients. For example, in countries with market penetration sometimes higher than 100% of the population, it is very important to retain customers. Additionally, studies show that the cost to retain a customer is lower than the cost associated with acquiring new ones [1].

The goal of this work is to detect customers about to leave the TELCO operator and create a predictor model. Furthermore, identifying the underlying causes of the client's departure is considered a major advantage. It opens the model black box, adding knowledge about the problem and allowing for customized campaigns, using this knowledge to create the best offer or campaign to target specific clients. To answer these questions, we resort to a dataset of raw events of a European TELCO operator. Using this data and performing some feature engineering to capture patterns in customer behavior, different models were created to predict customers that will not make any kind of activity in the next 30 days.

This work focuses mainly on pay-as-you-go clients with uneven top-ups during their lifetime. Throughout this article, the methodology used is described along with the results and how to attain insights into why some clients will leave the company. The framework relies on cutting-edge state-of-the-art algorithms to predict and explain the reason behind clients leaving an operator. Results show that the prediction algorithm achieved good performance in major metrics. Therefore, this algorithm could be an important add-on to current TELCO operation systems, being able to predict and mitigate clients' departure.

# Related work

We are, by no means, the first to explore churn aiming to gain insights related to customers abandoning a company. In this section, we present some articles that are related to (and also inspired) the work presented in this article.

## Neural networks and images

In [2], a variant approach of usual churn prediction was studied, where customers and their actions are codified in images. Each image is associated with a distinct customer and is composed of three different parts: the first one contains the customer's ID to identify each customer; the second one has the events converted to red-green-blue (RGB) code; the third one contains the information whether that customer is a churner or a non-churner. The image is codified as follows: a table containing the values of each day per row, and the number of events (calls and messages) and recharges in each column. The values are then codified to RGB code (different values have a different codification and color).

Then, a neural network is implemented, with the images as the inputs of this network. This method is different from standard approaches, where it is used tabular information from datasets. Although the authors present good results, the heaviness of the algorithm and the need for computational resources are unclear.

## SHAP

In [3], a new approach to interpreting machine learning models is proposed, making the impact of each variable on the model and on each output clearer.

In this article, the shapley additive explanations (SHAP) method is presented to understand the behavior and contribution of variables globally and individually. Globally, a graphic is represented with all variables, arranged in a decreasing form of impact, and with the positive or negative impact of this variable on the model. A graph is also made for each variable, where it is possible to see the impact of the fluctuation of the values taken by that variable. Individually, it is shown how to represent the score associated with each customer's ID with the impact that each variable had to lead the customer to have that score.

This approach was used in this work and is one of the foundations of explainable machine learning, leading to new insights viable to downstream systems to make the best offer to the client.

## Sliding window

In [4] it is proposed a new study with a novel approach through a sliding window.

In this work, the sliding window is studied by varying the training set in the time window both in period and size. Thus, it is possible to understand how the model is affected when the training set period is longer or shorter and when the window of this set is slid. It is also possible to see the impact on the model when doing some pre-processing of the data and some statistical analysis.

# Proposed methodology

This section describes the data sets used in this proof-of-concept, the methodology used, and finally, the feature engineering made over the raw events.

## Churners

In a concise definition, churn corresponds "to the loss of customers for a given service in a certain period of time" [5]. Another important definition is the churn rate that measures the percentage of customers leaving the company and consequently the end of their journey with that specific product or service. Bearing this in mind, the identification of churners is an important aspect for any company delivering some sort of product.

In this specific research problem - TELCO companies - the goal is to detect and predict which customers are more likely to leave the service. Altice Labs' Active Campaign Manager product [6] will be responsible for all the campaigns carried out to retain these customers, as it presents all the functionalities needed to interact and give products and services to final customers.

Companies tend to distinguish between voluntary churn and involuntary churn. Voluntary churn corresponds to a voluntary departure on the client's part, either to change to another service or to move to another company. Involuntary churn is used when the reasons for departing are external to the customer, e.g., change of home location or death. In this case, involuntary churn is not included in the analyses and in the studies carried out, focusing on voluntary churn, which usually occurs due to factors related to the downfall of the customer-company relationship and which the company is generally capable of reacting.

Another important aspect of churn is the division into two major groups:

1. A group of customers with a loyalty contract, generally designated as postpaid clients, with a recurrent monthly invoice being charged to the customer;

2. A group of customers with pay-as-you-go mobile phone cards, generally defined as prepaid clients, that have non-regular events (e.g., recharges, voice calls, or SMS).

This work will focus on prepaid clients since postpaid clients' churn is a more straightforward problem to solve: there is a loyalty contract between the customer and the TELCO, with a clear termination date. Prepaid clients, on the other hand, provide us with a more challenging problem. The group is more heterogeneous and showcases an irregular lifecycle with higher uncertainty associated with their revenue, which will test the limits of our approach.

Although it is possible to pinpoint clients that will leave a company after several months without events (e.g., 90 days) with high accuracy, this approach may sometimes identify them too late. Thus, it seems more appealing to detect churn in earlier stages, as downstream systems responsible for interacting with the clients will not be able to retain them since they already have abandoned the company.

Considering the reasons mentioned above, the decision was to consider a prepaid customer as a churner if he/she had not made any recharge or event in a certain period of time, i.e., 30 days.

## Data used for churn detection

This study used three types of customer data: historical data of top-ups, events (calls, messages, and mobile internet), and the customer profile.

The data is a daily aggregation of events and recharges. It contains information related to the amount of the top-up, calls made, and duration, amongst others. All sensitive fields were anonymized for this work, complying with the European General Data Protection Regulation (GDPR), ensuring no personal information was used. Afterward, we added other features related to the customers' profiles, and applied filtering and aggregation to build the characteristics of those profiles.

## Feature engineering

Data preparation and quality play an important role in machine learning-based solutions, and the adoption of data-centric strategies can substantially leverage model performance. Thus, a feature engineering approach was taken starting with the datasets described above and finishing with a dataset containing many features calculated from these records. These new features have different granularities (1 month, 3 months, and 12 months) and aim to capture changes in customer behavior over time.

Feature importance [7] was used to measure the benefit of adding the new variables. Weight of evidence and information value [8] were also used for feature selection [9]. The weight of evidence measures the contribution of each individual feature for the target (in this work, churn) and ranks their predictive strength. This method is usually performed pre-modeling, enabling to inspect variables for bias, strange patterns, and measuring the effect of missing values, thus identifying the best strategy in each situation. This approach allowed us to identify the top 27 more relevant features for the problem, which significantly improved the results, as shown in the next section.

## Methodology

The methodology used in this work to train and test the models consists of two steps: firstly, we used the data described in the 'Data used for churn detection' section, selecting month M to train the model. The classification of non-churner or churner is made according to the activity or inactivity of the customer in the next month (M+1); secondly, data from month M+1 is used to test the model, where predictions are validated using churners and non-churners from month M+2. This methodology is illustrated in **Figure 1**.

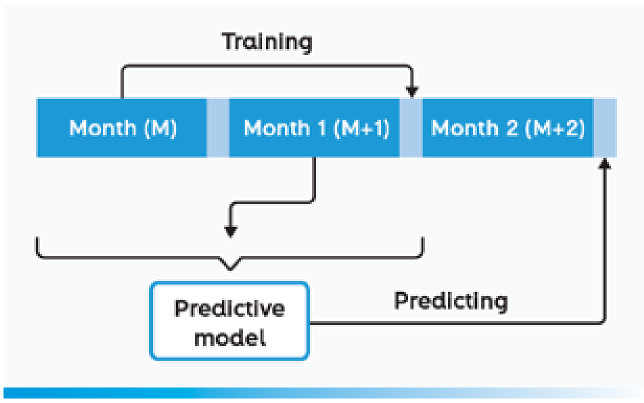


**FIGURE 1** – Methodology used in this study

As an example, thinking in M as June, M+1 as July and M+2 as August, the model is trained with the data of June and the information of July to classify each customer as churner or non-churner. After that, this model is used with the data of July to predict the churners of August. This methodology can be used as a sliding window to predict the following months.

To evaluate this approach and to understand the models' trustworthiness in predicting churn customers, several classification metrics were used as precision, recall, and f-score [10]. These metrics compare the model result with the observed outcome (classification in churn vs. non-churn), resulting in true positives, false positives, and false negatives present in the list of churners. The threshold (TH) used to separate the two classes was chosen to optimize one or more metrics mentioned before. The classification of true positives, false positives, false negatives, and true negatives was done according to the rules present in **Table 1**.

# Results

This section presents the results obtained using four different models, along with the results using SHAP values to interpret the final model and determine which variables have the most impact on the results. It is important to notice that we are only presenting the final results, for the sake of conciseness.

## Models

Choosing which models to use was a task that started with a broad list, from which models were culled if they did not show good enough performance (precision, recall, F1-Score, accuracy). In the end, we were left with four different algorithms: XGBoost [11], LightGBM [12], Random Forest Classifier, and Gradient Boosting Classifier. We used the same data to train and test all algorithms, obtaining comparable results, as presented in **Table 2**.

| | Predicted churner >= TH | Predicted churner < TH |
|---|---|---|
| **True churner** | True Positive | False Negative |
| **True non-churner** | False Positive | True Negative |

**TABLE 1** – Classification of true churners and predicted churners for a specific threshold

| Algorithm | Precision | Recall | F1-Score | Accuracy |
|---|---|---|---|---|
| **XGBoost** | 65% | 61% | 63% | 89% |
| **LightGBM** | 48% | 84% | 61% | 83% |
| **Random Forest Classifier** | 63% | 65% | 64% | 89% |
| **Gradient Boosting Classifier** | 54% | 78% | 64% | 86% |

**TABLE 2** – Metric values of the different algorithms with a threshold default (50%)

With these results, a graphical representation was built to evaluate the impact of different thresholds in precision, recall, and accuracy for all four models so that, when varying the threshold value, we are able to understand the behavior of these metrics and which models would be the best to continue this study. This is shown in **Figure 2**. In this phase, a model is considered to have a good performance if it presents linear and stable recall and precision in all the spectrum of the threshold. Hence, the marketeer can vary the threshold depending on the campaign purpose.

According to the results obtained in **Table 2** and **Figure 2**, XGBoost and Random Forest Classifier were chosen to move on. Both presented encouraging results, and therefore it was necessary to understand which of the two is the best model. Thus, the selected models were compared in three different and consecutive months, and the results are presented in **Table 3**, which shows that the results of the XGBoost and the Random Forest Classifier models are very similar.

Since we have a higher slope for lower thresholds, which allows having a wider range of results to suit each campaign and following the principle of Occam's razor or the law of parsimony ("when you have two competing theories that make exactly the same predictions, the simpler one is the better") [13] we decided to choose the XGBoost model. This is due to the fact that this model allows to apply a threshold that presents linear results on the combination of recall and precision.

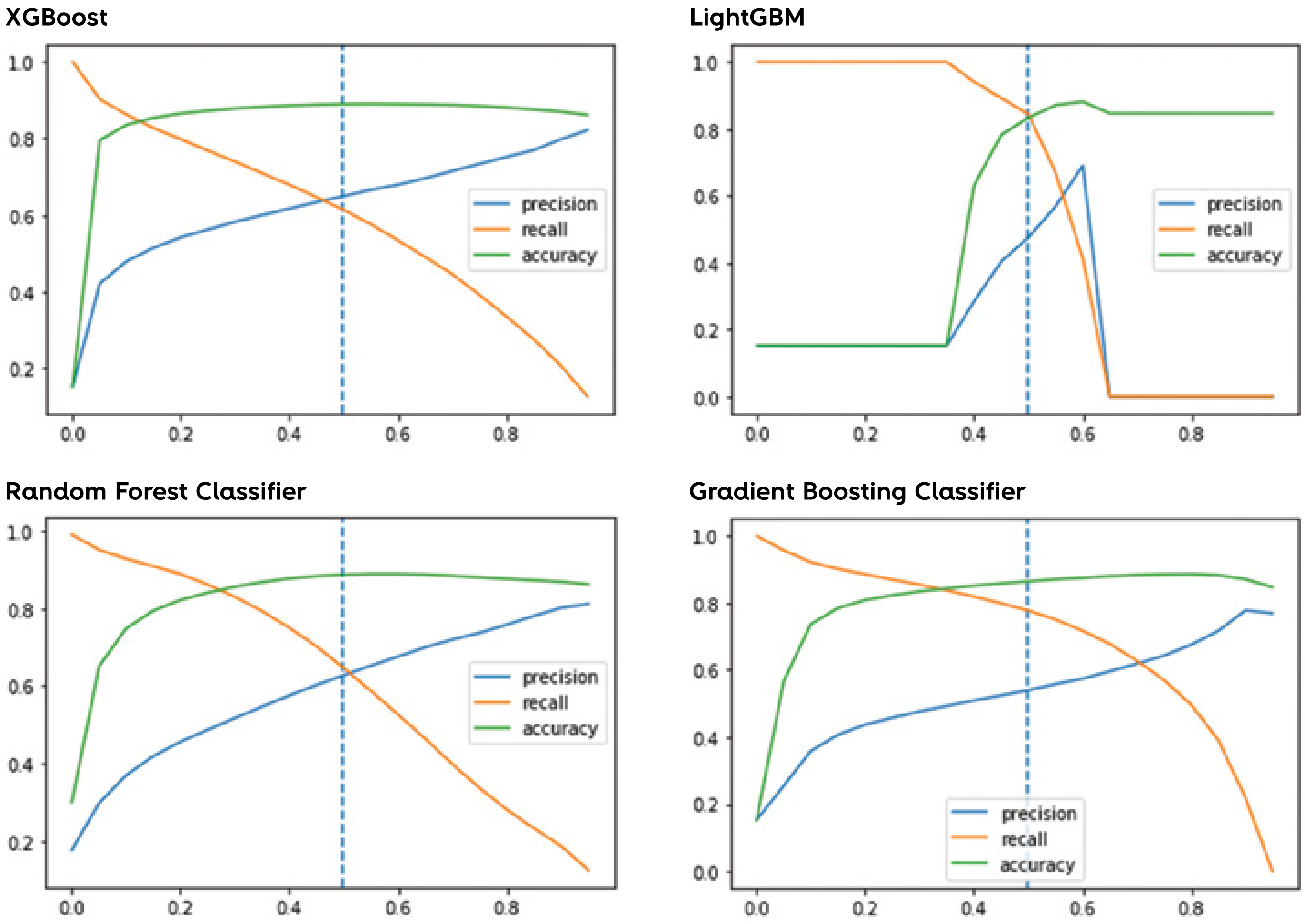


**FIGURE 2** – Model performance across different thresholds

**XGBoost**

| Month to predict | Precision | Recall | F1-Score | Accuracy |
|---|---|---|---|---|
| **February** | 65% | 61% | 63% | 89% |
| **March** | 67% | 67% | 67% | 90% |
| **April** | 69% | 70% | 70% | 90% |

**Random Forest Classifier**

| Month to predict | Precision | Recall | F1-Score | Accuracy |
|---|---|---|---|---|
| **February** | 63% | 65% | 64% | 89% |
| **March** | 66% | 69% | 67% | 90% |
| **April** | 67% | 73% | 70% | 90% |

**TABLE 3** – Metric values of the two best algorithms with a threshold default (50%)

## Model explainability

In this study, the need arose to interpret the model and understand how the variables impacted our model and outputs. SHAP was used to explain our model in a global and individual way. Globally, the model can be explained by **Figure 3**, where it is possible to observe the variables represented in decreasing form of impact on the model. Can also see that some features have a very clear impact on the model: those that are more reddish points on the right, which positively impact our model, i.e., the higher the value of this feature, the greater the probability of a customer to do churn; also, those that are more reddish points on the left, which negatively impact our model, i.e., the higher the value of this feature, the lower the probability of a customer to do churn.

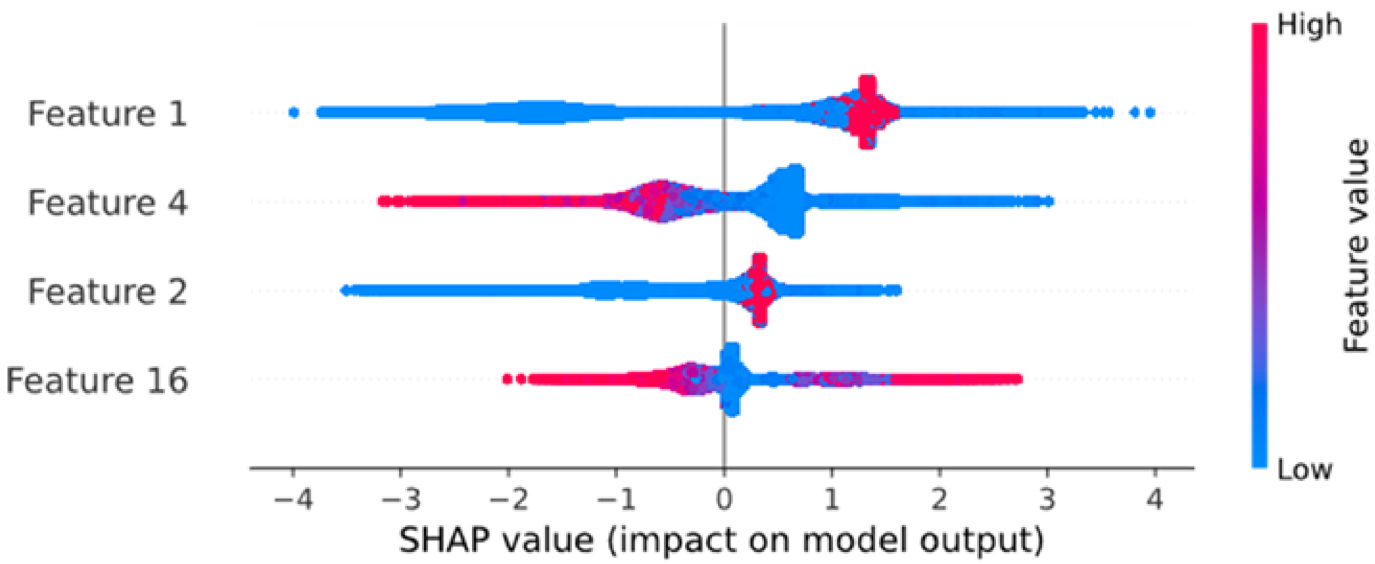


**FIGURE 3** – Global impact of the features on the model using SHAP values

The impact of a feature on the output can be seen in **Figure 4**. In this figure, it is possible to see that lower values of the feature are associated with lower values of the final output. Higher values of the feature are associated with higher values of the final output.

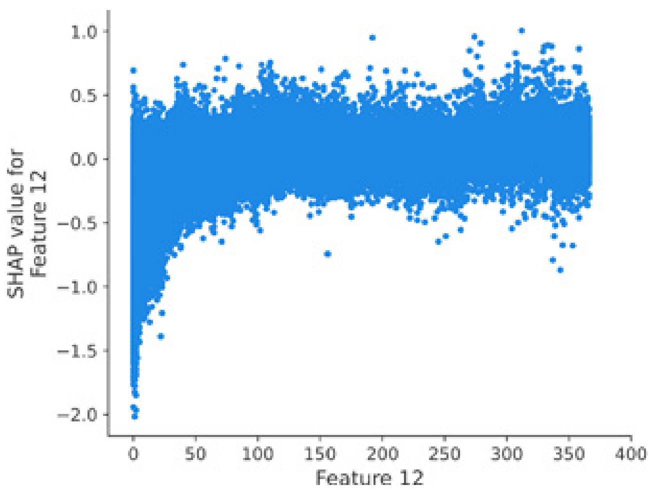


**FIGURE 4** – The impact of a feature on the output

Individually, it is possible to understand which features contributed the most to the customers' scores. For example, in **Figure 5**, it is possible to see a customer whose score starts at the average score of all customers. Its value increases or decreases when we add the features associated with this customer. Red features increase the score value, and blue features decrease the score value. In the end, we arrive at the probability of this customer to do churn. It is also possible to see which features had the most positive and negative influence, and which had the greatest impact on the final score.

# Conclusion and future work

In a world full of services and with the cost of acquiring a new customer much greater than retaining customers already in the operator, detecting who is about to leave a company proves to be a crucial differentiator factor in TELCO companies. This is a trend on the rise with company investment in this field increasing.

This study clarifies that churn prediction is possible and very feasible through raw datasets and feature engineering. The built model reveals a great performance, and the obtained results allow us to choose the strategy that better suits the campaign purpose. The fact that the model is supported by previous studies with an academic base already demonstrated and consolidated shows even greater viability for this project.

In the future, we pretend to develop and build a pilot project with a European TELCO operator to understand better different campaign strategies. Using A/B tests to test different models and test which ones provide better results will further increase the knowledge about this method and its advantages, drawbacks, and lifts for the TELCO company.

We also intend to validate the results, the model, and our strategy with other operators outside of Europe with a vast prepaid client base, to prove the robustness and adaptability of our model in different social contexts.


**FIGURE 5** – Individual impact of the features on the model using SHAP values

# References


**[1]** S. Syed, H. Halaoui, F. Hicham, M. Mahmoud, and M. Mansour, "Analytical imperatives for telecom marketers in emerging markets," vol. 11, no. 2, pp. 19–36, 2014

**[2]** A. Wangperawong, C. Brun, O. Laudy, and R. Pavasuthipaisit, "Churn analysis using deep convolutional neural networks and autoencoders," pp. 1–6, 2016, [Online]. Available: http://arxiv.org/abs/1604.05377

**[3]** S. M. Lundberg and S. I. Lee, "A unified approach to interpreting model predictions," *Adv. Neural Inf. Process. Syst*., vol. 2017-December, no. Section 2, pp. 4766–4775, 2017

**[4]** A. K. Ahmad, A. Jafar, and K. Aljoumaa, "Customer churn prediction in telecom using machine learning in big data platform," *J. Big Data*, vol. 6, no. 1, p. 28, Dec. 2019, doi: 10.1186/s40537-019-0191-6

**[5]** W. Verbeke, K. Dejaeger, D. Martens, J. Hur, and B. Baesens, "New insights into churn prediction in the telecommunication sector: A profit driven data mining approach," *Eur. J. Oper. Res*., vol. 218, no. 1, pp. 211–229, Apr. 2012, doi: 10.1016/j.ejor.2011.09.031

**[6]** Altice Labs, "ACM Active Campaign Manager," 2020. https://www.alticelabs.com/products/campaign-management/

**[7]** Fabian Pedregosa *et al*., "Scikit-learn: Machine Learning in Python," *J. Mach. Learn. Res*., vol. 12, pp. 2825–2830, 2011, [Online]. Available: https://scikit-learn.org/stable/

**[8]** L. Zhang, H. Ray, J. Priestley, and S. Tan, "A descriptive study of variable discretization and cost-sensitive logistic regression on imbalanced credit data," *J. Appl. Stat*., vol. 47, no. 3, pp. 568–581, Feb. 2020, doi: 10.1080/02664763.2019.1643829

**[9]** K. Larsen, "Information Package Vignette," *The Comprehensive R Archive Network*, 2016. https://cran.r-project.org/web/packages/Information/vignettes/Information-vignette.html

**[10]** D. L. Olson and D. Delen, *Advanced Data Mining Techniques*. Springer, 2008

**[11]** XGBboost Developers, "XGBoost Documentation," 2021. https://xgboost.readthedocs.io/en/latest/

**[12]** "LightGBM," *Microsoft Corporation*, 2021. https://lightgbm.readthedocs.io/en/latest/

**[13]** W. M. Thorburn, "Occam's Razor," *Mind*, vol. XXIV, no. 2, pp. 287–288, 1915, doi: 10.1093/mind/XXIV.2.287

# 05 Who matters? An intelligent approach to user segmentation

**Vera Estanqueiro, University of Coimbra, CISUC, DEI**
veralucia@student.dei.uc.pt

**Ricardo Paiva, University of Coimbra, CISUC, DEI**
rjpaiva@student.dei.uc.pt

**Nuno Lourenço, University of Coimbra, CISUC, DEI**
naml@dei.uc.pt

**Penousal Machado, University of Coimbra, CISUC, DEI**
machado@dei.uc.pt

**Nuno Pimenta, Altice Portugal / MEO**
nuno-pimenta@telecom.pt

**Maria Manuel Castro, Altice Labs**
maria-m-castro@alticelabs.com

Customer segmentation allows marketers to engage with each customer in the most effective way. Since the marketer's goal is usually to keep the customers loyal and engaged with the company, it is important to model how any particular marketing action will influence the customer, enhancing the way contacts are made while smartly improving what is offered.

## Keywords

Marketing campaigns; Customer segmentation; CRM; Customer loyalty; Influencers; User based

# Introduction

Nowadays, telecommunications companies want to provide their customers with specialized services tailored to their needs and taste. At the same time, companies need to keep their contacts to the minimum to avoid user fatigue, which might result in the loss of a customer. One way to provide these services is to look at how customers interact with other individuals by studying their call detail records (CDR) to understand their social circles. We can use social network analysis techniques to extract metrics from a contact network to study and detect relationships between individuals and infer which customers belong to the same social group, such as work or family. Using this information, companies can adjust the offers to their customers.

Deciding when and how to make an offer to a customer is also of the utmost importance. They are usually made through marketing campaigns in which the company directly contacts a client using a specific communication channel (e.g., voice, SMS, e-mail). However, the increasing number of advertisements over time has reduced the effect of marketing on the public [1], making users prone to ignore a contact if it is performed at an inconvenient time or channel. As such, both the timing and channel of contact are two key factors to consider when defining the best approach for marketing campaigns.

As we can see, companies face several challenges regarding the management of the relationship with the clients. These issues might be mitigated by the creation of client profiles using segmentation techniques to understand their social and contact preferences.

In this article, we describe an ongoing effort that aims at solving these challenges. In concrete, we propose models to analyze the social networks of customers and their preferred methods of communication, to determine who are the most influential customers in a network, as well as their social groups. Additionally, we design and develop a series of machine learning (ML) models to assist in designing marketing campaigns, namely deciding on when and how to contact a particular customer using their contact history.

# Customer relationship management and artificial intelligence

Customer relationship management (CRM) can be defined as "*the building of a customer-oriented culture by which a strategy is created to acquire, enhance the profitability of, and retain customers, that is enabled by an IT application; for achieving mutual benefits for both the organization and the customers*" [2].

The CRM concept is directly connected with marketing goals. The article [1] defines the three different marketing activities described below, where artificial intelligence (AI) solutions are commonly used.

Customer segmentation is the division of potential customers, in a given market, into discrete groups. This division is based on both client's needs and behavioral traits such as buying characteristics, responses to messaging, and marketing channels. Using all this information, data mining techniques allow to uncover groups with distinct profiles and lead to rich segmentation schemes with business meaning and value.

Direct marketing campaigns are a type of advertising campaign that seeks to achieve a specific action in a selected group of clients. The communication can be established by e-mail, SMS, telemarketing, or another channel. Data mining can be used to automate the process of building models to identify the right customers to contact.

Marketing strategies are defined by organizations considering their context. The telecommunication area is particularly interesting to be further discussed. Knowledge discovery in this field include the following [3]:

- **Customer loyalty —** customers repeatedly switch providers, or "churn," to take advantage of attractive incentives by competing companies. The companies can use data mining to identify the characteristics of customers who are likely to remain loyal once they switch.
- **Call detail records analysis —** telecommunication companies accumulate detailed call records. By identifying customer segments with similar use patterns, the companies can develop attractive pricing and feature promotions.

In particular, call records have a special interest for the purpose of this project, and for that reason, they will be further detailed.

Call detail records are routinely collected by telecommunication providers to detect congested cell towers in need of additional bandwidth [4] and to bill customers for cellular usage. Besides this, they are a powerful source of information. For each communication between individuals, the mobile operator keeps a CDR containing the type of call, phone numbers involved in the transaction, time, duration, cell tower ID, among others. The contents of the communication are not revealed through the CDR, as they only store communication-related properties. They can also include SMS records or any other official communication transaction. For example, CDR can be combined with the physical addresses of the cell towers to obtain the approximate location of where a particular call was made or received.

This type of information can be used to create networks, which can be analyzed using network analysis techniques. Through this analysis and considering the amount of data generated every day, telecommunication companies and other entities can investigate the relationship level between individuals, their mobility patterns, population distribution in different locations, among others.

Associated with the creation of the networks and the necessity of giving meaning to this type of information, another concept arises: social network analysis (SNA). SNA is a collection of methods that use networks and graph theory in order to understand relationships, interactions, and communication patterns between individuals. These networks are based on relational data and can be applied to various scientific fields [5].

The networks are usually represented using graphical structures called graphs. They are composed of two fundamental components: nodes and edges. A node is an intersection point that can represent a wide variety of individual entities (e.g., a person, a location, an organization). At the same time, an edge is a link between two nodes, and it can represent several kinds of relationships between entities. Edges can have two attributes associated with them: direction and weight. Generally, in social networks, the weight of a link could represent the duration, emotional intensity, or frequency of interaction between two nodes [5]. Over time, different metrics were developed to provide insights into the structure of the network and understand how the different actors are linked to each other. Given the nature of this article, we will only focus on a few commonly used centrality measures such as degree, betweenness, closeness, and page rank. These metrics attempt to examine the influence level of a given node in relation to the network using centrality procedures. A node with a high centrality value represents an actor with high social strength, meaning that it is well connected to a large proportion of the remaining network nodes. Throughout the literature, these types of actors are also known as network influencers [6].

## Exploratory data analysis

Exploratory data analysis allows us to understand what information we can use from the raw data and helps us make decisions about what approaches to take. In order to facilitate this whole process, dashboards were developed using the Python language [7], with two of its modules: Plotly [8] and Dash [9].

Voice call records are our primary data source. We started our study by analyzing the time distribution of the data to find out if there are different patterns in different timelines. With weekly time intervals, we began by checking the days and hours with the highest traffic. In general, the interval between 10am to 8pm has the most traffic, corresponding to 82% of total calls. On the other hand, people make the most phone calls on Monday and Friday afternoon, with a big break at weekends (17%). Next, we wanted to study the call patterns per number to see if customers had the same calling pattern in different weeks, and we found some abnormal values. When selecting the numbers with the highest number of calls, we found that those that came first received over 600 calls per week. As the records are related only to private customers, we consider this a high value. In total, six numbers with these characteristics were detected. To better understand this, a call duration filtering was implemented. We found that the call times for some of these numbers are always zero but, for others, this is not the case, and there is no clear distribution over time. Finally, to inspect the recurrence of calls between numbers, we checked the number of inbound and outbound calls between two pairs of numbers. By examining different numbers, we were able to see some recurrence of calls between pairs of numbers over the different weeks. It was also possible to confirm that there are a lot of numbers that only receive or make calls.

# Segmentation

Customer segmentation allows marketers to engage with each customer in the most effective way. Since the marketer's goal is usually to keep the customers loyal and engaged with the company, it is important to model how any particular marketing action will influence the customer. The following topics describe all the work that has been done to segment customers and improve the way contacts are made.

## Social-based

### Influencer detection

The identification of the most influential individuals (also called influencers) in the customer base of a given company is important to plan and create new campaigns. Companies can use the influence and outreach of the influencers to support their brand, product, or service, and in some cases, drive their purchases.

Currently, we have developed a model that builds a network of interactions between clients, computes centrality measures, and uses them to rank clients by their influence.

The construction of the interaction networks is crucial for our analysis. The analysis of these structures allows us to study the relationships between individuals and how the flow of information occurs. Our dataset consists of data collected in September and October 2020. For each week of those months, voice call detail records were grouped by number according to the following structure: ("caller number", "called number", "number of calls").

Each entry in the result set corresponds to an interaction between two individuals. Using this information, we built a network of interactions between clients, where each client corresponds to a node in the graph, and the number of calls is used to define the weight of the edge between the two nodes. In addition to being weighted, the networks produced are also directed, since the direction in which calls are made is important for us to understand how the information flows. For example, nodes that establish connections in both directions between themselves may represent clients that establish a relationship of greater proximity.

Influencer detection is based on four state-of-the-art centrality measures: degree (both indegree and outdegree), betweenness, PageRank, and closeness. The final influence of a client is computed using these four metrics, and customers with the highest influence values are the influencers in the network. The following **Figure 1** shows a visual representation of a subset of the interactions network, where the radius of the node is proportional to the level of influence. The nodes colored blue, identified as "389550", "446753" and "399172", are considered influencers of this sub-network since they obtained a higher centrality score. Node "190976", colored yellow, is the selected node when graphing the sub-network.

## Operator classification

Identifying the mobile operator of the customers becomes an important factor from the point of view of a telecommunications company. Call logs record to which mobile operator a particular call was made. With this information, we are able to associate the operator to a certain number as long as it has received a call. So, for

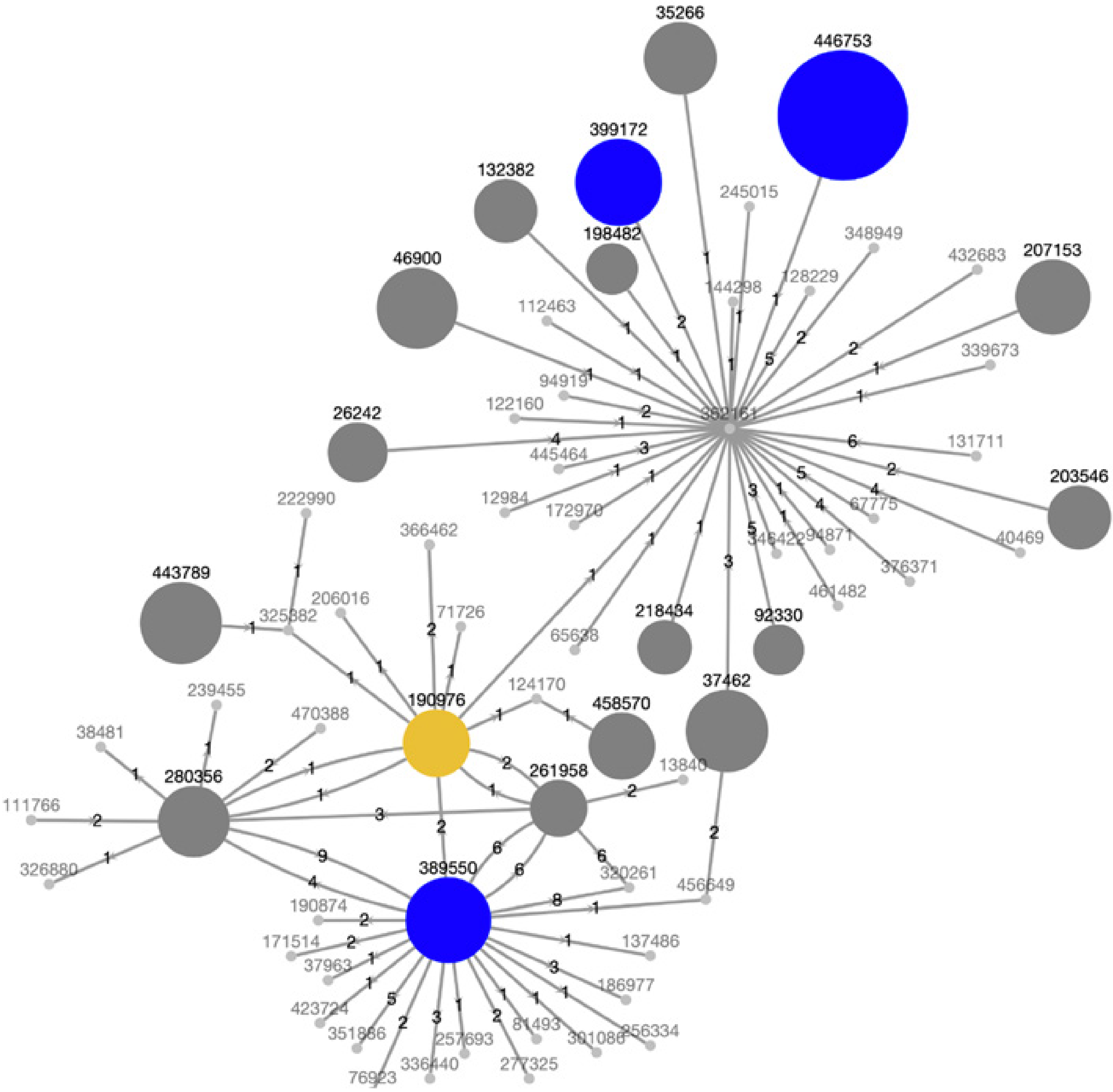


**FIGURE 1** – "190976" – Partial network with three top influences

each number in our database, we fetched the last call it received and identified the operator code associated with the registry. There was a concern to retrieve the last record to avoid situations where a particular customer changes operator during the time interval of the data. For customers where we have no records of incoming calls, the mobile operator is classified as undefined. **Figure 2** illustrates the partial network of the number "71369", where it is possible to analyze the mobile operators associated with each number. Each node color is related to a different mobile operator, and in this network, we observe the presence of three of the biggest telecommunication companies operating in Portugal (NOS, Altice, and Vodafone). This data was all stored in the database for future use.

## Identification of communities

To determine the communities, we developed a method that divides the interaction network into groups where each customer is associated with a group. Since recent data convey that the average household size in Portugal is 2.5 individuals [10], it was important to use an iterative process to obtain smaller divisions of the interaction network. The results can be found in **Table 1**.

As shown, the algorithm produced 31389 communities for the two months of traffic that make up our dataset. Analyzing the results in a more detailed way and considering the objectives of the decomposition of the network into communities, we can highlight two fields from those presented above. First, we assume that the number

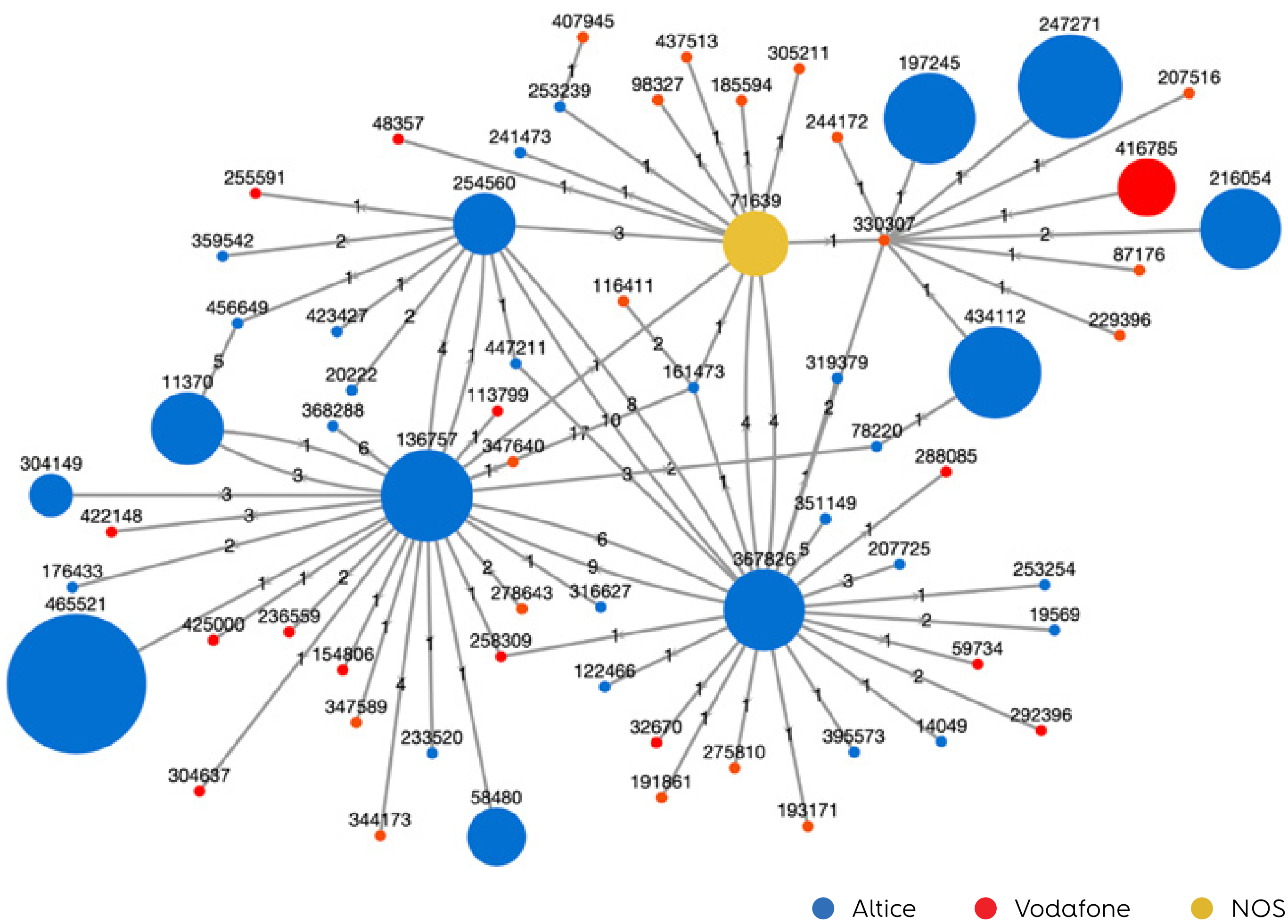


**FIGURE 2** – "71639" – Partial network with mobile operators

| | |
|---|---|
| **Total number of communities** | 31 389 |
| **Total number of communities smaller than 5 elements** | 4983 |
| **Total number of communities with size greater than 5 and less than 10 elements** | 9640 |
| **Total number of communities with size greater than 10 and less than 20 elements** | 11 736 |
| **Total number of communities with size greater than 20 elements** | 5030 |
| **Average size** | 13 |
| **Size of the biggest/smallest community** | 616/1 |

**TABLE 1** – Identification of communities

of communities with less than five elements can be representative of households. Taking into account the average number of elements per household in our country, we think this is an acceptable number, also considering the characteristics of the city of Coimbra where the data used refers to. As Coimbra is known as the student city, we also highlight the average size of the communities. Usually, young people tend to relate to a lot of people being work or university colleagues. In this way, we consider that communities with a size around this value may translate relationship groups, be they work or social ones.

When analyzing the set of results, we found the existence of two communities with a high number of elements, the largest one consisting of 616 elements. By analyzing the constituent elements, we found out that the numbers that received a large volume of calls during the period under study were inserted in these communities. This type of outliers is produced since these numbers are connected to a large number of customers in the interaction networks.

# User-based

## Determining client's availability

Another possible way to perform customer segmentation is based on the client's availability for being contacted, which will allow us to create groups of clients with similar behavioral patterns. Discovering the best hour to contact a customer can be seen as a classification problem composed of fifteen categories (each category corresponds to an hour between 8am and 10pm). In particular, the goal is to create an hour rank to contact a client. The impact of this challenge is mainly felt during voice communications as both actors need to be available and engaged in the action. So, only voice interactions are considered for the purpose of this study.

The construction of the dataset that will support the model is an important step. We started to filter communications registries by calls' duration as we consider that this factor can be used as an indicator of the client's availability. Each entry of the dataset contains information about the interaction, as well as information about the client. Other types of features related to the customer call behavior are useful in this context, such as the number of weekly communications. The goal is to inject more information about the client that could indicate availability per hour. This data can be extracted from CDR.

Furthermore, the client's availability to be contacted depends not only on the time of the day but also on the day of the week. This information was discovered when we analyzed possible temporal patterns hidden inside the data, in which some weekdays showed a higher concentration of phone calls. Taking this into account, we defined two different approaches. In the first one, the model does not consider a distinction between weekdays. The second one takes into account that users have different availability that depends on the day of the week.

## *Non-weekday-based approach*

The way we addressed the problem was to directly use the clients' features as the input to a supervised ML algorithm and the hours when an interaction with the CRM occurred as the target. This approach gives us the answer to one part of the problem. The creation of the ranking per customer was the essential component of the model that required a careful plan. Using this approach, the algorithm should be able to learn to identify each hour based on the input characteristics. Then, when confronted with the new example, it must label the client with the most suitable hour. Considering that we want to find the top five best hours to contact a client, the described process needs to run five times per client. In each run, the output (the hour assigned to the client) is saved. Afterward, we remove this option from the training dataset, which invalidates that hour to be chosen again as the best hour to contact the client.

The test results of this approach can be seen in **Figure 3**. The graphic represents the gain per hour of each approach compared to a base model implemented to simulate the percentage of the company's current successful communications.

Examining the figure, we can see that the model shows gains at every hour. The smallest gain value is 9% at 11am, and the maximum gain value is 28% at 3pm. In general, the proposed approach has an average gain of 17%, compared to the success rate of the one currently used to establish communication with the clients. This is a positive indicator that the company could benefit from the implementation of an approach, as suggested in this section, that defines which clients should be contacted at each hour and increases the success rate of their answering. However, we would like to point out that the results should be analyzed with caution as the percentage of success of the base model is an estimation of the reality.

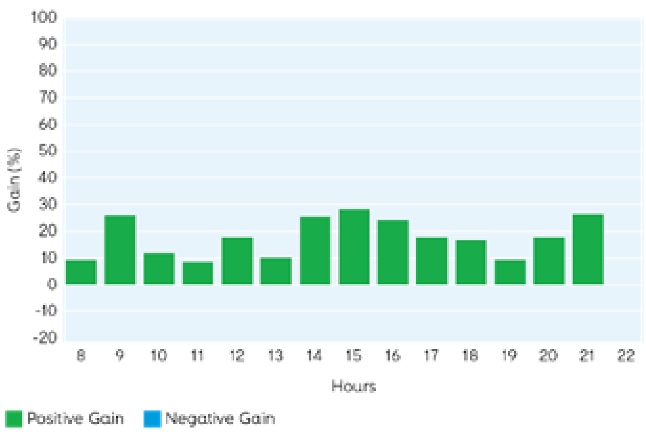


**FIGURE 3** – Results of the ML model to the hour identification

## *Weekday-based approach*

Considering the results from the temporal data analysis, we will now take into account the weekday dimension. To accomplish such a task, we developed a model that returns an hour ranking per client per weekday. To achieve that, we needed to split the initial dataset by the day of the week of each contact. The result is one sub-dataset for each working day. Then, these sub-datasets will be used as the input of a supervised ML algorithm in such a way that five models are trained (one per working day). Each client's features are given to the models to obtain the best hour to be contacted per day. Once more, as the goal is to find the top five best hours to contact a client, the described process needs to run five times per customer, deleting the previously assigned hour from the sub-dataset in each run.

The test results can be seen in **Figure 4**. The graphics represent the gain per hour per day of the week of each approach compared to a base model implemented to simulate the percentage of the company's current successful communications.

A brief perusal of the results in **Figure 4** shows that we have a superior number of hours with gains than those with losses on all weekdays. Tuesday, Wednesday, and Thursday have a more uniform gain per hour, with only five hours without gains. Particularly, 8am and 8pm to 10pm could be considered difficult to predict. We want to point out that the hours with a perfect gain rate had few representative samples in the testing dataset, and

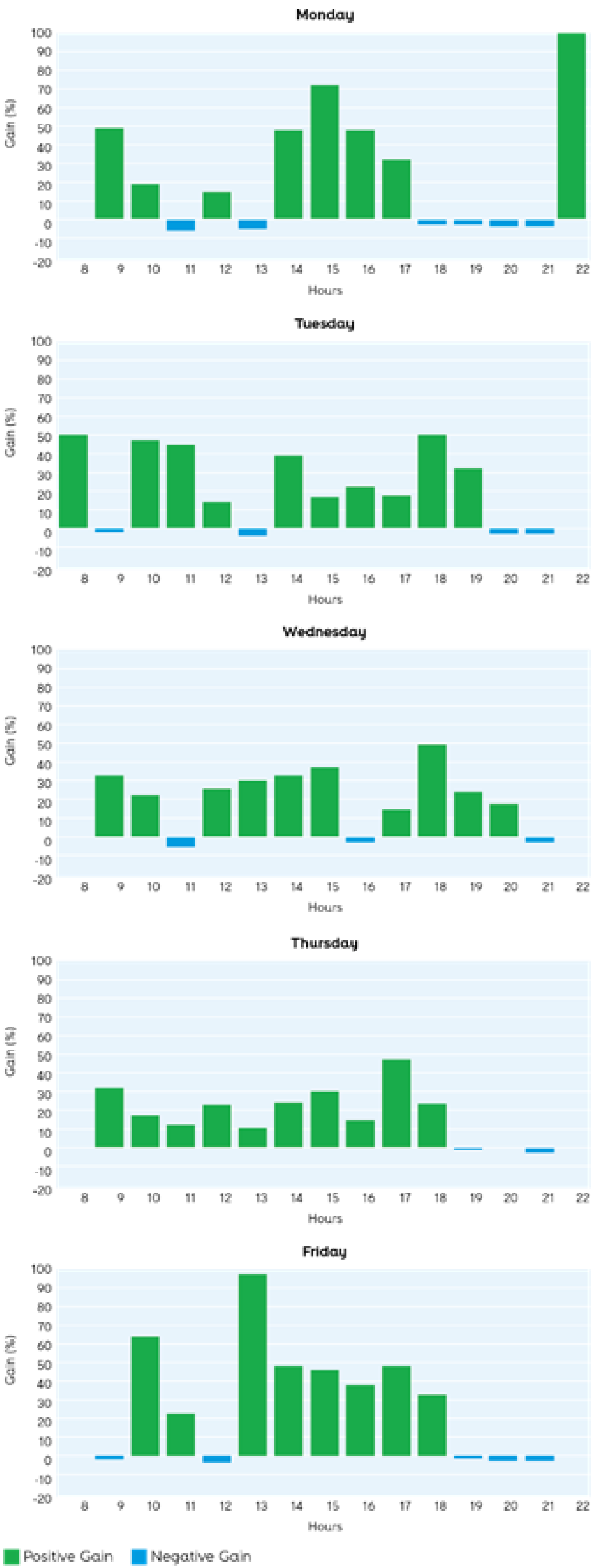


**FIGURE 4** – Results of the ML model to the hour identification for weekday-based approach

this factor contributed to their score. Nevertheless, globally, the results obtained show an average gain of 23%, which shows that the implementation of a model as described in this section could support the decision-making process when it comes to making calls schedules based on working days. Once more, these results should be considered with caution as the percentage of success of the base model is an estimation of the reality.

## Determining the communication channel

In addition to the client's availability for being contacted, deciding the communication channel is an important factor to make the customer segmentation. Voice, SMS, and e-mail are the most common means of interaction. Taking this into account, we can see this challenge as a classification problem with three labels. Our goal is to create a rank of channel preferences per client as it can help companies better manage their resources without compromising efficiency.

The dataset is composed of samples extracted from the set of interactions' records between the client and the CRM, and information about voice calls, SMS, and GPRS consumption. The goal is to transform and select data that can represent successful voice and e-mail interactions, and add samples of clients that choose the SMS channel for daily communication. The labeling process is distinct for all three categories. Voice communications are filtered based on the call duration; we considered just the client-to-CRM e-mail interactions to resolve this problem; and the customers with SMS communications between the defined thresholds were labeled as potential SMS users.

### *Three-class classification approach*

Considering this, the identification of the best way to establish communication with the client can be obtained through a supervised learning algorithm. This case is a three-class classification (voice, e-mail, and SMS). The challenging part is to label each sample as the thresholds of a successful contact must be well defined, and each customer can fit into more than one category.

In this approach, the goal is to return the channel ranking per client. To complete such a task, the ranking model follows the same approach defined in the previous problem. The process runs two times per customer: the first iteration is a three-class classification whose output is the best channel to contact that client, and the next iteration is a binary classification between the other two classes. The last label is added to the final of the ranking.

The test results of this approach can be seen in **Figure 5**. The percentage of success corresponds to the number of clients correctly predicted in each class. Graphics A, B and C represent the best, the second, and the third-best channels to establish contact with a customer, respectively.

The results show that a high percentage of clients are correctly classified regarding just the preferred channel. We have an almost 50% success rate in both e-mail and voice channels and 75% for the SMS channel. Globally, and considering Graphic A, we have about 56% of success rate, which means that the channel assigned to the clients matches their communication preferences. Additionally, we can observe that these values are better than randomly selecting a channel, where each class will have an approximate success of 33%. It is worth mentioning that the SMS rate can be influenced by the definition of a potential SMS customer user.

The three graphics show progressive losses from the best channel success rate to the third-best channel success rate. This behavior confirms that the model can correctly classify a higher rate of clients when confronted with three labels in contrast with the two-label classification (represented by Graphic B) and the addition of the last label (represented by Graphic C). Thus, we can conclude that it will take fewer iterations to successfully reach out to a customer compared to a random selection, as the probability of choosing their preferred channel decreases with the increase of the channel rank position.

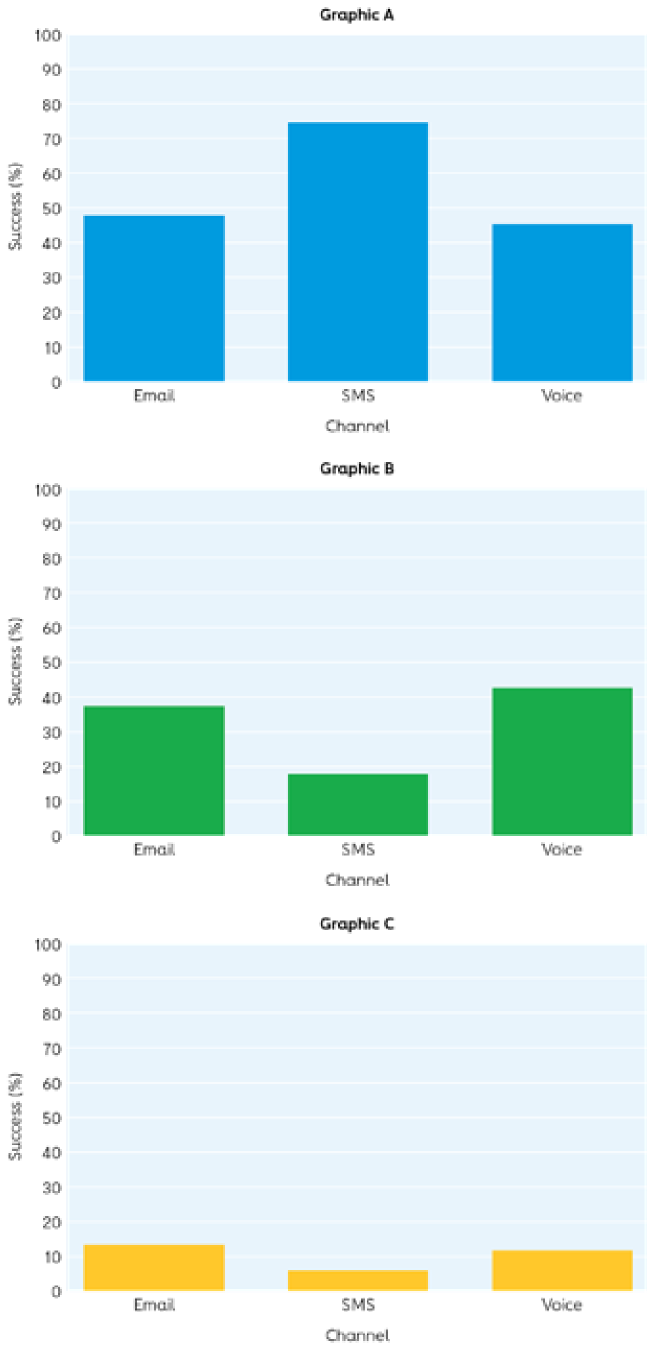


**FIGURE 5** – Test results of the model that predicts the rank of channel per client

# Conclusion

In this study, we propose two approaches to perform customer segmentation based on their communication patterns and social interactions. For this purpose, we analyzed the social network of customers to identify the most influential customers in a network and their social groups. Additionally, we designed and developed ML models to assist in the process of deciding when and how to contact a particular customer. We believe the design of marketing campaigns could benefit from the results of this work.

Regarding the social-based customer segmentation, we are able to identify the influencers of a network and also to characterize the clients depending on their mobile operator. Companies could use these results to adapt their marketing strategies and campaigns to the customers' profile. In addition, we developed a model to detect communities inside a calls' record network.

Concerning the customer segmentation based on the user's characteristics, the models created to predict an hour ranking per client showed positive results as they showed gains for every hour compared to the baseline model. Meanwhile, the approach to assigning a channel rank to each customer achieved better results than an approach based on random search.

In general, the study presented in this article proved to have applicability in the telecommunications field, particularly for the marketing department. Since the process of designing a campaign to the way the customer is contacted, profiling a client is a key factor in maintaining their customers and attracting potential ones.

# References


**[1]** Q. K. Al-Shayea, "Evaluating marketing campaigns of banking using neural networks," *Lect. Notes Eng. Comput. Sci.*, vol. 2 LNECS, no. July 2013, pp. 759–761, 2013

**[2]** S. Moro, P. Cortez, and P. Rita, "A data-driven approach to predict the success of bank telemarketing," *Decis. Support Syst.*, vol. 62, pp. 22–31, Jun. 2014, doi: 10.1016/j.dss.2014.03.001

**[3]** A. Clauset, M. E. J. Newman, and C. Moore, "Finding community structure in very large networks," *Phys. Rev. E*, vol. 70, no. 6, p. 066111, Dec. 2004, doi: 10.1103/PhysRevE.70.066111

**[4]** B. C. Csáji et al., "Exploring the mobility of mobile phone users," *Phys. A Stat. Mech. its Appl.*, vol. 392, no. 6, pp. 1459–1473, Mar. 2013, doi: 10.1016/j.physa.2012.11.040

**[5]** S. Tabassum, F. S. F. Pereira, S. Fernandes, and J. Gama, "Social network analysis: An overview," *WIREs Data Min. Knowl. Discov.*, vol. 8, no. 5, Sep. 2018, doi: 10.1002/widm.1256

**[6]** N. R. Al-Molhem, Y. Rahal, and M. Dakkak, "Social network analysis in Telecom data," *J. Big Data*, vol. 6, no. 1, 2019, doi: 10.1186/s40537-019-0264-6

**[7]** "Python," *Python Software Foundation*, 2021. https://www.python.org/

**[8]** "Plotly," *Plotly*, 2021. https://plotly.com/

**[9]** "Dash," *Plotly*, 2021. https://dash.plotly.com/

**[10]** PORDATA, "Dimensão média dos agregados domésticos privados," *Fundação Francisco Manuel dos Santos*, 2021. https://www.pordata.pt/Portugal/Dimensão+média+dos+agregados+domésticos+privados-511

# 06 Clouds bring sunshine to networks

**Rui Calé, Altice Labs**
cale@alticelabs.com

**Miguel Freitas, Altice Labs**
miguel-r-freitas@alticelabs.com

**Miguel Santos, Altice Labs**
miguel-c-santos@alticelabs.com

The constant search for better and faster digital services puts additional pressure on digital services providers as they need to provide networks that can be quickly adjusted to new demands. In the last few years, network evolution has primarily been driven by that need, bringing network functions to the software domain, separating them into their components, and deploying them where and when necessary, resorting to cloud technologies borrowed from the IT world.

## Keywords

Future networks; Cloudification; SDN; NFV; Softwarization

# Introduction

Communication services providers (CSP) have long initiated the journey towards digitalization by evolving their information systems to cloud approaches, resulting in deeper business insights and improved customer experience. The network, however, is a different story: we are just starting to scratch the surface of what cloud technologies, enabled by virtualization and software-defined approaches, can do for telecom operations worldwide, together with a full ecosystem of service-based architectures, open innovation, and development and operations (DevOps). 5G is a good example of how networks are starting to move in this direction. In fact, not only the 5G architecture was designed considering a cloud-oriented implementation, but all modern networks and the services they support will have to move in that direction.

This is particularly evident with edge computing: as the public clouds evolve from a few high scale data centers towards processing at the edge to enable low-latency and high-bandwidth applications, like those related to augmented reality (AR), virtual reality (VR) or internet of things (IoT), and 5G access network aligns to provide the edge with the needed communications functionalities, the whole network edge is evolving to use the same hardware and the same practices that cloud providers use [1][2].

Network cloudification, hereby considered as the process leading to the adoption of cloud technologies on the network, is the culmination of a process of network softwarization [3] and builds on the achievements (and limitations) of network functions virtualization (NFV) and software-defined networks (SDN). The desirable result: software-oriented networks able to cope with fast change and permanent service innovation.

This trend presents many technical challenges, but above all, it involves deep transformation on how the CSP and solution providers operate, both internally and within the ecosystem. Namely, the extreme acceleration on the development/integration/delivery cycles brings new approaches like DevOps and continuous integration (CI)/continuous delivery (CD) that create highly automated processes, not within reach of more traditional organizations. CSP seem to be gearing up, certainly pushed by the opportunity to swiftly evolve their service offerings and maintain their relevance in a world where just selling bandwidth becomes less and less profitable. **Figure 1**, using 2021 data, illustrates how CSP evaluate their own degree of preparedness:

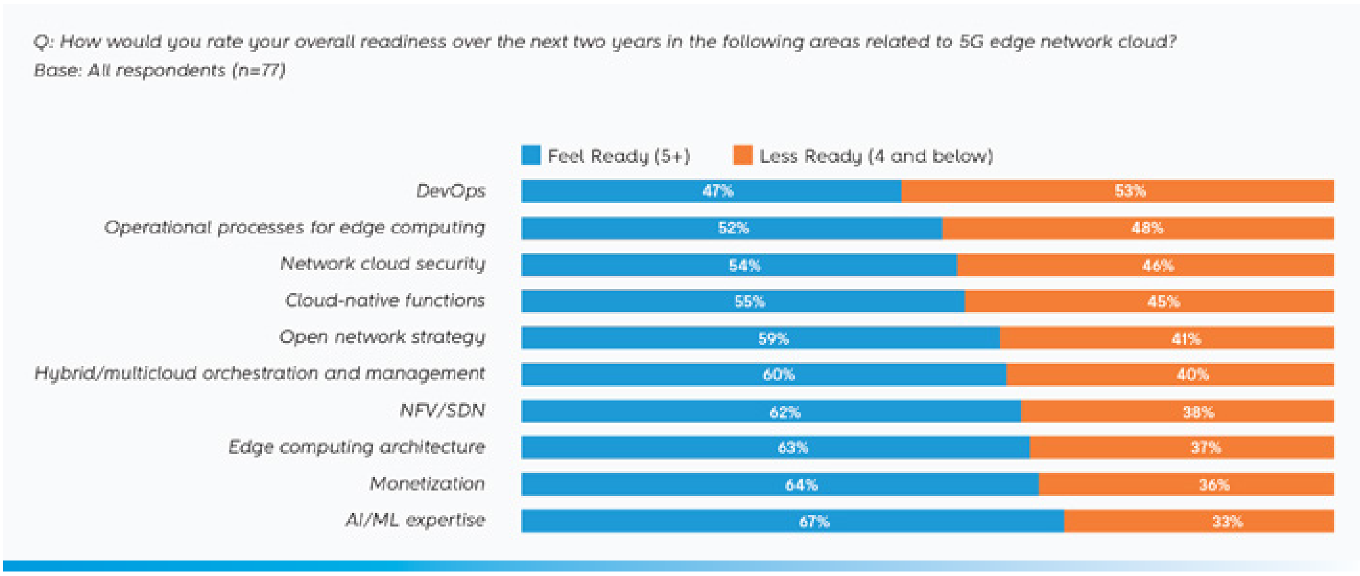


**FIGURE 1** – CSP readiness for network cloudification [4]

This article starts by addressing the whole network softwarization process, its reasons, components, and main actors. Then, it delves deeper into the architectures and technologies supporting Network Cloudification, finalizing with the Altice Labs' approach to this matter, using a concrete example: the virtualized broadband network gateway (BNG).

# Softwarization

The digitalization shift in the telecommunications world has led to significant pressure on the telecom operators to continuously increment their data networks capacity (as the number of connected devices explodes), bandwidth demand (as more data services are used simultaneously), and latency (as newer and more critical services need very close to real-time communication) to deliver faster and more reliable data services to their customers. The wide variety of data services and the rapid rate at which new ones are developed and commercialized today also means that telecom operators need to be able to quickly re-design parts of their network to cope with the specific requirements of some of those services.

To achieve such flexibility, mutability, and scalability, with a much bigger network capillarity, where network functions are evermore close to the end-user to provide more throughput and less latency, it is necessary to move away from the classical architecture – based on static deployment of vendor-specific hardware appliance characterized by monolithic functionality deployed at specific network locations – and adopt a much more dynamic architecture founded on what the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) defines as network softwarization: "an overall approach for designing, implementing, deploying, managing and maintaining network equipment and/or network components by software programming" [3]. Three main technologies/principles laid the ground for successful network softwarization: SDN, NFV, and cloud computing.

SDN [5] provides the foundations that allow operations to centrally define how a network function should treat users' traffic. It aims at making the network agile and flexible by introducing a software approach to the definition of how the hardware units – where the user traffic is processed – should behave across the entire network. These principles can be employed for managing a network function on the configuration/provision phases of the network setup and in real-time, where new processing rules can be applied depending on several conditions (e.g., type of traffic, source, destination, etc.). SDN approaches were boosted by another long-standing systems' architectural principle, the control and user plane separation (CUPS), where network systems are divided into two main parts: the user plane dealing with the user traffic and the control plane responsible for determining the behavior of user plane.

As per NFV [6], the virtualization of network functions allows new ways to design, deploy and manage networking services. NFV enunciates the process to decouple network functions from running on vendor and function-specific hardware, enabling the generalized use of commercial off-the-shelf (COTS) equipment for network functions. Virtualization allows the same computing environment (in its smallest instantiation set, it can be reduced to a single computing node) to run multiple independent systems at the same time, including all network traffic processing and the corresponding function's control software.

In the end, NFV makes it possible to instantiate a network function where and when it is needed. At the same time, SDN guarantees that traffic is correctly steered and the network function can be disaggregated and distributed as better suited.

More recently, the widespread adoption of cloud computing technologies across all types of industries and organizations has forced telecom operators to look at this completely new paradigm of developing systems and conducting operations. On the one hand, systems by design should now intrinsically assure elasticity and scalability of their workloads to extract the most benefits of a distributed cloud ecosystem and assure a quick response to always evolving service needs. On the other hand, the cloud computing principles, applied to the operation side of system management, bring a more flexible, dynamic, and automated way to answer the challenges to continuously deliver the best quality of experience to each and every customer.

The top six benefits of Network Softwarization and cloudification can be summarized in:

- Optimized allocation of computational resources;
- Centralized network control;
- Automated operations;
- Hardware and software vendor options;
- Network visibility;
- Fast time-to-market of new service.

The push to more open and dynamic networks also allowed the flourishing of open initiatives that took advantage of the decoupling from vendor-specific hardware to create and incentivize the production of open-source software that, in turn, allows the participation of more players thus leading to an ever-growing more pulsating and diverse ecosystem. The Open Networking Foundation (ONF) is one popular initiative in this area, but others like The Linux Foundation, the Open Compute Project (OCP), or the Telecom Infra Project (TIP) are also very relevant projects.

Several standards developing organizations (SDO) have also taken the concept of network softwarization and cloudification into their definition of next-generation networks both on wired and wireless technologies. The most relevant SDO for mobile network and systems – 3rd Generation Partnership Project (3GPP) – has adopted from the "get-go" softwarization principles in the definition of its fifth generation (5G) architecture [7], clearly separating user plane from control plane functions and defining a service-based architecture that suits perfectly with the principles of cloud computing. Similarly, the Broadband Forum (BBF), the leading SDO for fixed broadband network and systems, has been working on the incorporation of these principles on its latest technical reports where a new virtualized and disaggregated network architecture is proposed [8], covering all the path from customer premises all the way up to the data center. Other relevant SDO such as the European Telecommunication Standards Institute (ETSI), the Internet Engineering Task Force (IETF), and the International Telecommunications Union (ITU) also produce work of extreme relevance for the success of the proposed technology and paradigm shifts.

## Architectures and technologies supporting cloudification

CUPS paved the way into the initial stages of network function disaggregation, ensuring that basic principles from the software engineering domain, such as the single-responsibility principle (SRP), are respected and fulfilled. CUPS, however, only solves part of the scalability equation: existing networking software carries a heavy load of legacy code and dated software design patterns, even on the control plane side. Such artifacts are often called "monoliths", i.e., they follow a monolithic architecture in which functionally distinguishable aspects such as data input/output (I/O), processing, storage, and user interfaces are all tightly coupled and entangled together, instead of providing well-defined interfaces for component separation.

The solution to break the monolith is long known and has been extensively applied in the

IT world, as illustrated in **Figure 2**. It involves a controlled and methodic process of refactoring the existing codebase by applying a sequence of small behavior-preserving transformations. Strictly focusing on the control plane, one of the most known design patterns to accomplish this transformation is the so-called service-oriented architecture (SoA). In SoA, complex software systems are broken into individual functional pieces (services) that expose an interface contract (typically a web service) and communicate with other services through a bus, often called the enterprise service bus (ESB). Service separation in SoA promotes the horizontal distributiveness of the overall software system, the interoperability between software vendors and allows the use of multiple redundant copies of the same service as a fallback for high availability [9].

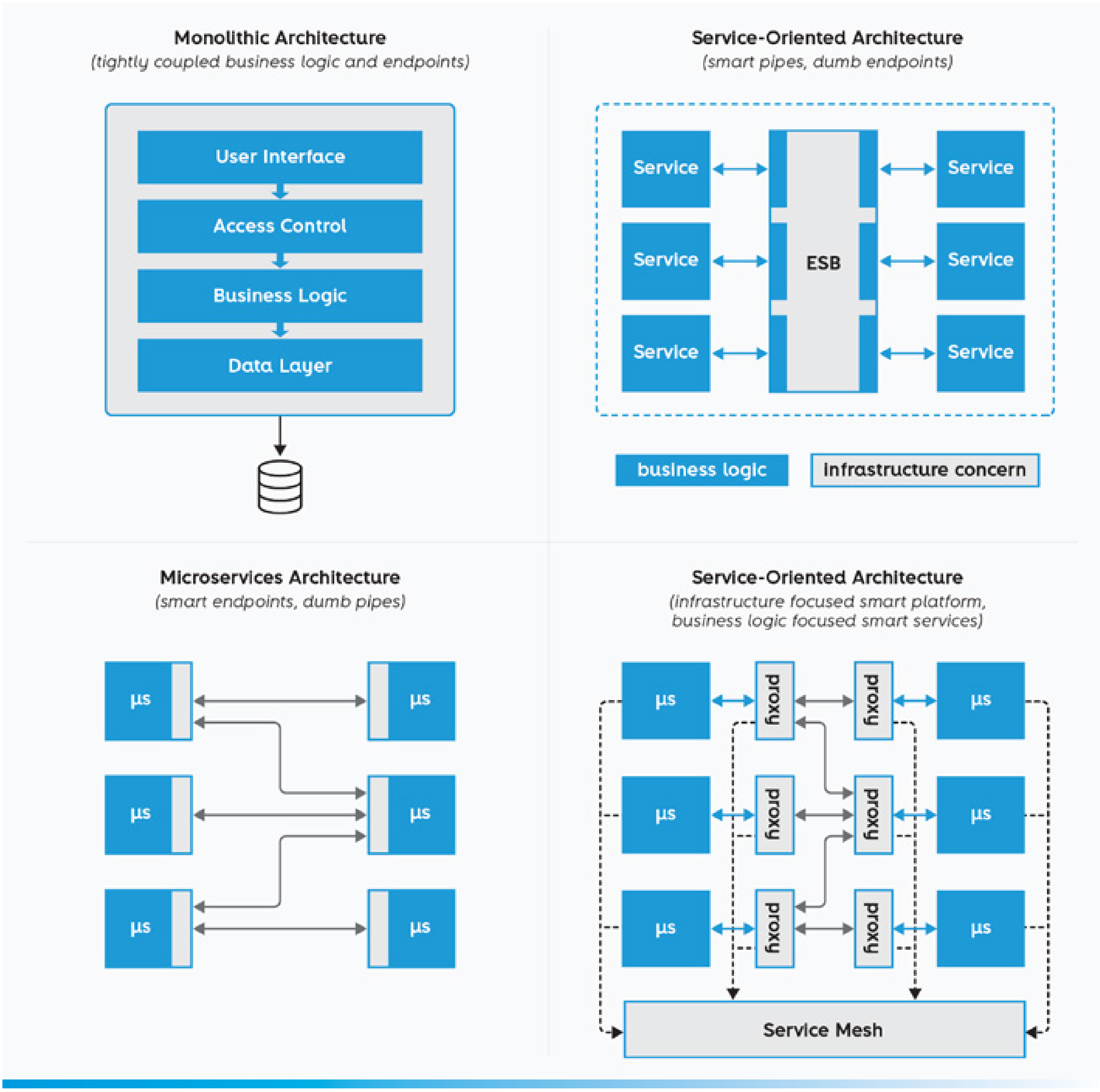


**FIGURE 2** – The evolution of software architectures from the monolith cloud-native microservices

Unlike classical distributed systems, where traffic distribution relied on the extensive use of load-balancers with statically provisioned service location, SoA tackles the problem from a different angle, with the introduction of a central discovery and registration entity (often a broker) which all the services use to register, authenticate, discover other services and send/receive data. If we look at modern network core architectures like 5G [6], it is no surprise to see that 3GPP chose to use a service-based paradigm in addition to the purely functional, interface-based approach. There, in addition to other core services, the network function repository function (NRF) provides a single record of all network functions available in a given mobile network, together with its profile and the services they support. Essentially, it allows network functions (NF) to discover other NF and to subscribe and get notified about the registration of new NF instances of a given type, having deep similarities with the broker role described above.

Despite the singular advantages of SoA, it should only be seen as an intermediary solution in the long network cloudification journey. SoA helps to decouple at a macro level but does not address the issues of granular scalability at the service level, i.e., it does not consider that the network function itself might be composed by a set of different components (a monolith in itself) nor the replication of these network functions across multiple datacenters. Additionally, SoA does not offer a clear solution to the load balancing issue.

This is of utmost importance in today's cloud-native world where, due to the advent of container-based virtualization, microservices are becoming the de-facto way to develop, ship, and distribute applicational workloads. The rise of the cloud-native application and the popularization of container orchestration frameworks, like Kubernetes, started to give visibility to complementary design patterns such as the service mesh architecture. The service mesh adds a layer of reliability, security (like mutual transport layer security (TLS) authentication), and observability features to a microservice application by inserting those features at the platform layer rather than in the application itself. Secure service-to-service communication is thus seen as a vital part of the application runtime behavior [10].

The service mesh architecture deeply inherits the CUPS principles. It is typically implemented as a set of scalable network proxies which run alongside the application code – sometimes referred to as "sidecars". The proxies handle the communication between microservices and are automatically injected by the platform. As such, they act as a point where the service mesh observability, security and tracing features are introduced with a minimal operational burden. Stateless in nature, sidecars can be seen as the user plane of the service mesh as they touch every request in the system without being aware of any configuration settings or policing. Features such as routing rules, request replication, load balancing settings, retrials, circuit breaking, etc., are inserted by a common control plane entity that ends up transforming all the individual data-planes into a transparent distributed system. The service mesh pattern might sound complex to understand and involve a lot of magic, but, in the end, it all comes down to the exceptional event-driven nature of modern container orchestration frameworks.

Let's take a closer look at the 3GPP 5G specification again. We can see the service mesh is now also a fundamental part of the architecture: in Release 16 (TS23.501) [6], the service communication proxy (SCP) was introduced to support the 5G service-based architecture (SBA) in distributed multi-access edge deployments, effectively adding support for services meshes within the 5G SBA.

While the control plane is following a clear architectural trend, favoring a cloud-native approach, microservice-based, by exploiting known design patterns such as the service-oriented architecture or the service mesh, the user plane is focused on a different challenge: the need for speed. Adopting the same principles in the user plane is severely affected by the caveats of network packet processing in virtualized environments.

In the (now) early days of I/O virtualization, network interface card (NIC) virtualization options were solely based on software. Between the virtual NIC associated with a virtual machine (VM) and the physical NIC of the server, the virtual machine monitor (VMM) was always the main active element in the virtualization process. Just like other I/O subsystems, network packet processing is interrupt-driven. When a packet is received by the server physical NIC, an interrupt request (IRQ) is sent to the server CPU, which must stop the currently running job to retrieve the data from the NIC buffers. Combining this with a virtualization scenario (e.g., a virtual machine) makes the situation even worse: the CPU core running the VMM needs to be interrupted but, after figuring out to which VM the packet must be sent, another interrupt must be generated so the CPU core(s) allocated to the VM can obtain the data [11]. The whole process is extremely slow and has a detrimental effect on the overall performance since the CPU constantly gets busy with non-strictly process-related tasks. In response to these problems, manufacturers have developed and standardized new approaches.

The single root I/O virtualization and sharing specification (SR-IOV) was released in 2007 by the Peripheral Component Interconnect Special Interest Group (PCI-SIG) as an extension to the PCI express (PCIe) specification to standardize the input-output memory management unit (IOMMU). With SR-IOV, a device such as a network adapter can separate the access to its resources among different PCIe hardware functions, splitting them into a PCIe physical function (PF) and one or more PCIe virtual functions (VF). VF can share physical resources such as memory and a network port with the PF and other VF [12]. In summary, SR-IOV allows network traffic to effectively bypass the VMM, moving it directly to the appropriate VF partition linked to a specific virtual machine context – a process known as direct memory access (DMA). **Figure 3** below illustrates SR-IOV.

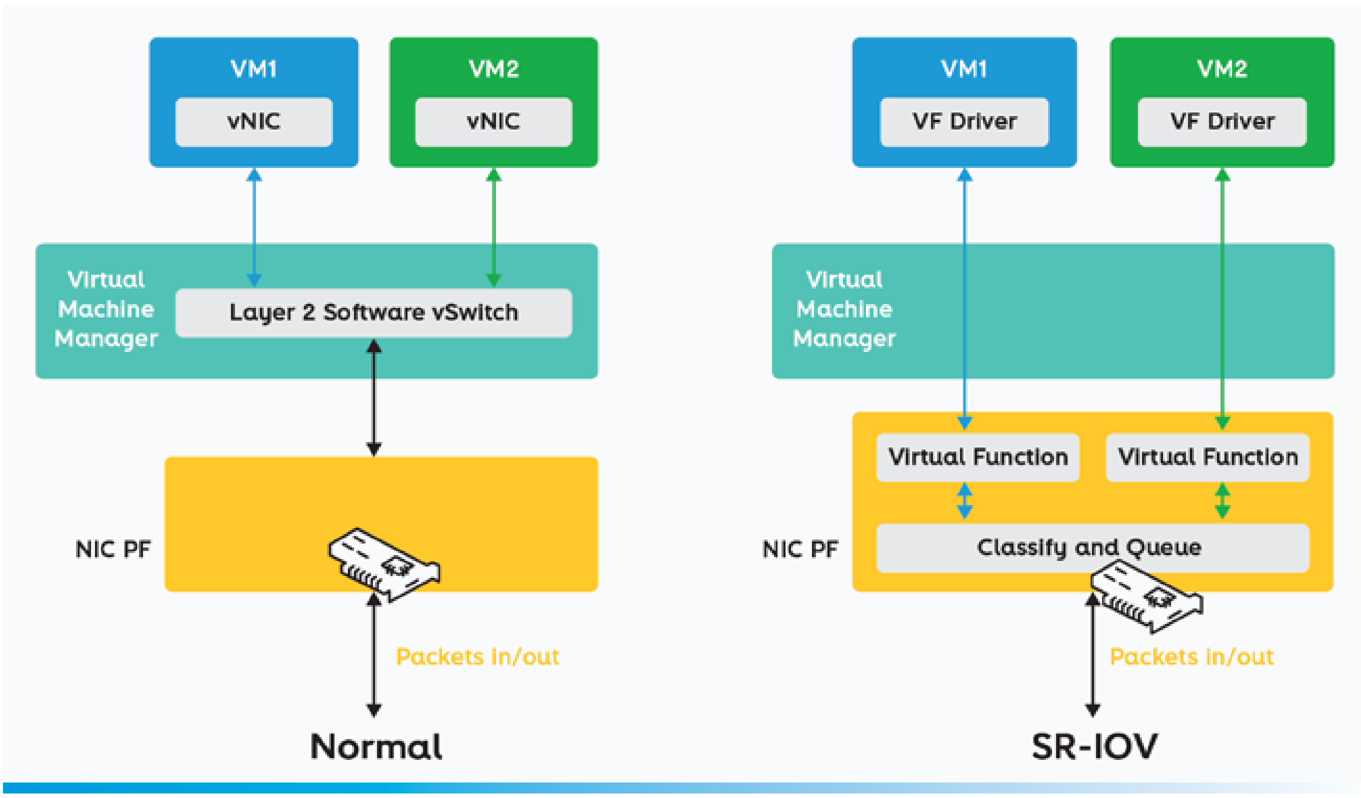


**FIGURE 3** – SR-IOV bypassing the VMM layer

SR-IOV solves part of the performance drawbacks of data plane virtualization. Still, it only covers the path between the physical NIC and the VM. It does not address further performance bottlenecks that may reside in the operating system (OS) of the VM itself. Modern operating systems, like Linux distributions, segregate memory and hardware privilege access into two main hierarchical domains: the kernel space (the uppermost trusted resource) and the user space (where the application workload runs). For applications to send or receive network packets, interrupts need to be generated, data copied between both memory regions, and system calls executed. System calls involve context switching: the context is switched from kernel mode back to user mode consuming a significant amount of resources. Progress was made on the kernel side with the introduction of the new programming interface (NAPI), which is able to combine interrupts with requests: the NIC first works in interrupt mode but, under periods of high traffic, the interrupt is disabled, and the system periodically polls a queue for new packets. Nevertheless, without relying on other strategies, the performance of Linux user-space network applications is still far from ideal [13].

This fact has led some networking software to extend the user plane logic to the kernel space, with the development of support Linux kernel modules (LKM) loaded at runtime and without the need of recompiling the kernel or rebooting the machine. A noticeable example is the default operation mode of OpenvSwitch (OVS), a known virtual switch implementation. OVS inserts an LKM that maintains an exact-match flow cache of recently forwarded packets, updated from user space via an inter-process communication (IPC) mechanism. Since only the traffic that does not have a corresponding entry in the cache needs to make the IPC context switch, OVS is said to have production-grade forwarding performance. Note, however, that LKM may introduce security risks (custom code with kernel privileges) and are also not portable (they depend on the kernel version).

To overcome the above limitations, the extended Berkeley packet filter (eBPF) recently arose as a way to execute packet filtering logic as bytecode at the kernel space. Unlike LKM, eBPF bytecode is just-in-time compiled and verified by a set of tools that reside within the kernel. Ultimately, it runs on a restrictive and self-contained in-kernel VM, providing a safe environment for applications to package kernel-level code and interact with protected hardware resources while still having shared memory constructs accessible from user space [14]. The express data path (XDP), which combines eBPF benefits, was later introduced as a means for user-space applications to directly read RX packet pages out of a kernel driver without allocating any buffers or software queues. A direct access facility that still accounts for the presence of (and is provided by) the network stack of the kernel itself [15].

The use of kernel facilities like eBPF and XDP in virtualized network applications is still in its early days. Alternative “non-kernel” user plane acceleration approaches, like the data plane development kit (DPDK), are rather mature and have already been proven successful by a wide range of applications. Just like how SR-IOV bypasses COTS servers’ VMM layer, we can say DPDK does the same for the Linux kernel. DPDK is a set of libraries that can be used to implement user-space drivers for NIC and fully realize the data plane in software with control over traffic queueing, memory, and buffer management. The framework can implement zero-copy DMA into large ring buffers (using memory hugepages) and, at the same time, it can rely on a polling mode for packet acquisition, just like NAPI [13]. **Figure 4** shows the various possibilities for data plane acceleration under Linux.

As it bypasses the kernel networking layer, DPDK encouraged the development of purely software-based network stacks. Vector packet processing (VPP) is likely the most prominent example: a graph-based processing pipeline where custom functionalities (plugins) can be developed as new nodes in the overall graph [16]. Other projects like OVS also provide an alternative data path for DPDK enablement. It is important to refer that all those user plane acceleration facilities - even DPDK

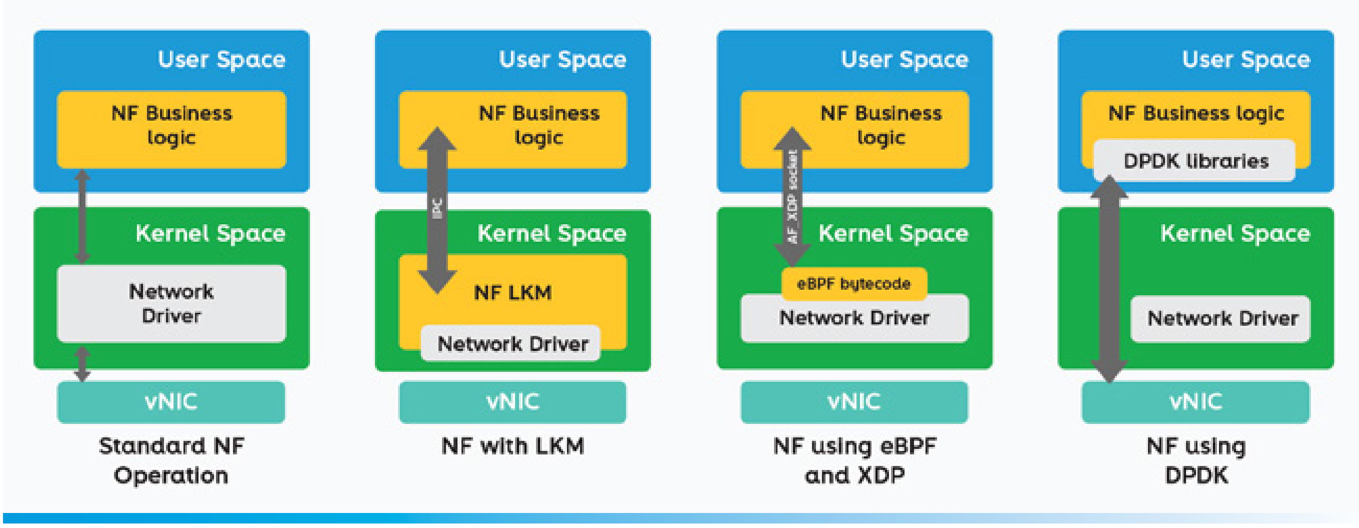


**FIGURE 4** – Data plane acceleration options in Linux-based systems

- are compatible with the microservices approach and modern container runtime orchestration frameworks. Kubernetes, for example, has adopted the container network interface (CNI) specification for managing network resources on a cluster with plenty of available plugins.

As seen, DPDK (and NFV in general) can place a significant strain on the processing capacity of the server CPU. When multiple gigabits of data need to be processed per unit of time, it might be desirable to offload some of the networking processing functions to dedicated hardware. In this field, a worth mentioning is deserved to smart NIC and programmable hardware switches, which employ specialized processors, field-programmable gate arrays (FPGA), to power their offload capacity [17]. Their FPGA can be programmed with standard development tools by taking advantage of high-level user-plane pipeline programming languages like P4 [18].

Features such as load balancing, encryption, packet encapsulation, deep packet inspection, or other intensive I/O tasks can be realized in hardware rather than software, saving the precious CPU cycles only for the control plane workloads.

All things considered, and as Frederick Brooks mentions in his software engineering classic “The Mythical Man-Month ”, we can say there is no “silver bullet” when it comes to virtualizing and cloudifying network functions. Multiple paths are available, and options should be carefully chosen in light of the expected scale, throughput, and other design requirements. Nevertheless, one thing we know for sure: the days of the network function monolith are now long gone.

# Altice Labs' approach

Altice Labs is pursuing its own strategy for network softwarization/cloudification, first of all by adapting its portfolio to cloud-based solutions. Also, to support a structured and systematic approach, Altice Labs has defined its own view for the access and edge networks, aligned with the ongoing standardization effort and best practices.

The diagram in **Figure 5**, available on next page, illustrates the high-level architecture defined by Altice Labs for a softwarized network edge which is thoroughly described in a former article [19]. Here, aspects like a virtualized infrastructure, CUPS, and function disaggregation are evident and define a framework for Altice Labs' network portfolio evolution.

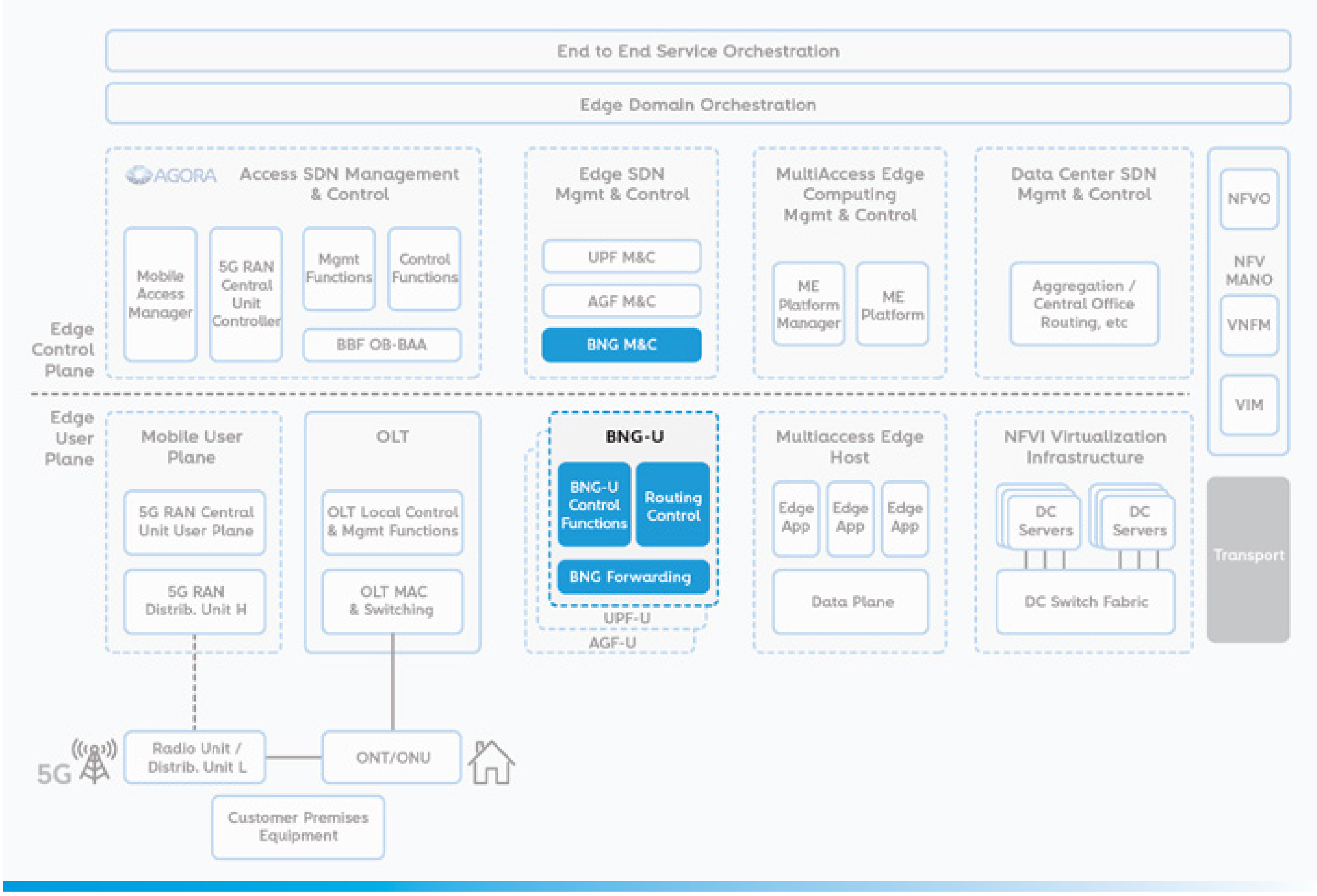


**FIGURE 5** – Altice Labs' edge architecture

Based in this architecture, corresponding to the highlighted area in **Figure 5**, and already capitalizing on the benefits described above, new products are being developed. One example is the virtualized BNG (vBNG) case, in which the disaggregated and cloudified approach can give rise to a next-generation product and also create a foundation of functional components that will be available for many other products and solutions.

The BNG plays a central part in nowadays fixed broadband networks as it is responsible for the interconnection of the access network and service networks (e.g., private service networks, telecom operator's service networks, internet). Often, its functional scope also includes assuring layer 2/3 connectivity between access and service networks, IP traffic routing, customer IP assignment and management, QoS enforcement, session accounting, lawful interception, multicast traffic (for IPTV), and network address translation (NAT).

Traditionally, as with all other network functions, the BNG is delivered as a vendor-specific appliance (running on vendor-specific hardware). As already discussed in this article, this type of approach presents several shortcomings for successfully tackling the challenges raised by nowadays demand for very fast response to new service requirements, which may imply network architectural changes.

In Altice Labs' point of view, the natural path for the BNG is the adoption of the network softwarization principles (as it is currently being defined by BBF in its TR-459 series) [20] and its development and delivery following cloud-native software principles.

The first step for the development of a vBNG was the functional separation between the control plane and the user plane. **Figure 6** shows that separation in three levels:

- The control plane layer (CP) is where all the control services for the different functionalities reside and is responsible for determining the system's behavior as a whole;
- The data plane abstraction layer (DPA) is responsible for the close control of the SDN switch and behaves as a middleware between the switch and the control plane functions and, together with the SDN switch layer, forms the user plane of the system;
- The SDN switch layer is responsible for switching and forwarding customer data packets.

In this architecture, the control plane is divided into services (using a micro-services approach) that are independent and are responsible for a specific set of functionalities. They are deployed using containers and managed by a Kubernetes cluster. This way, each service can be instantiated and adapted individually to respond to a specific demand, largely reducing the impacts on the system. The adoption of a cloud-native approach allows for zero-touch and minimal downtime when introducing new or augmented services that require changes in the system and/or the network.

The user plane (DPA and SDN switch) is also deployed using containers managed by a Kubernetes cluster providing the desired degree of flexibility to easily create and deploy new network configurations. Currently, the SDN switch used in the vBNG is the OVS, which has the advantage of being instantiated on COTS servers with x86 architecture, thus allowing computational resource sharing with other vBNG components and/or network functions. Additionally, the OVS has inherently available some packet acceleration options that allow its use in scenarios demanding very large throughputs. Other approaches, based on OCP compliant SDN switches, are currently under analysis as an alternative to the OVS to address higher performance requirements. Regarding the DPA, this layer includes an SDN controller that controls the underlying SDN switch and exposes a set of API (configuration, control, and

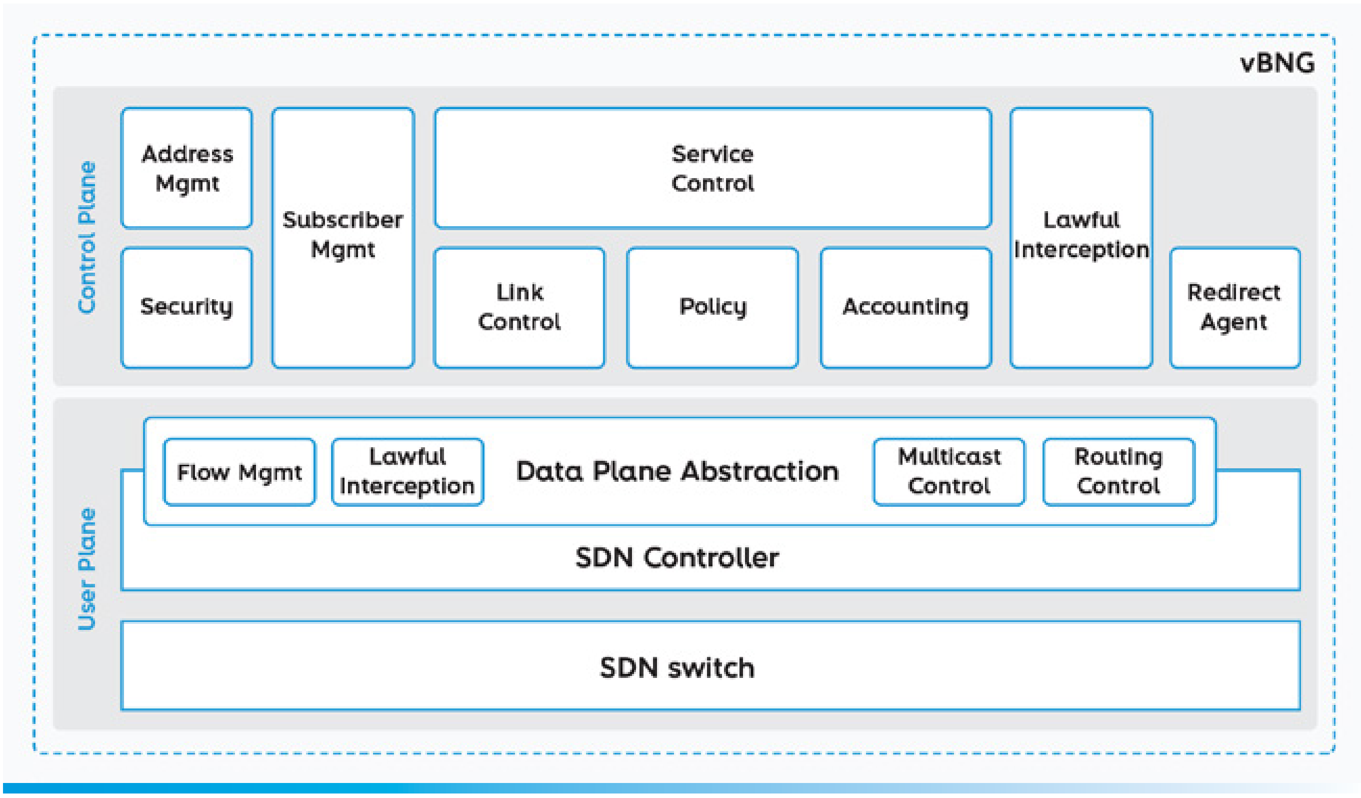


**FIGURE 6** – Altice Labs' vBNG architecture

packet redirection) to the CP. This approach assures an independence of the CP from the selected SDN controller as the DPA is able to create an abstraction on the specifics of each SDN controller northbound API.

The adoption of CI/CD methodologies on the development cycle allows the implementation of a much more agile process of releasing and delivering new versions, minimizing service impacts, and guaranteeing service continuity, which is paramount as changes become more frequent due to all the factors explained in previous sections.

Finally, the architecture designed for the vBNG provides the necessary tools to introduce a much more efficient way to operate the system as it allows several deployment architectures with logically centralized control plane and distributed user plane.

# Conclusion

With the maturity of the technologies described above and the vibrant ecosystem that is now extending from CSP and traditional solution providers to Internet hyperscalers and open-source communities, networks are certainly up for deep transformations. The relation built on many years of mutually beneficial collaboration between CSP and large telecom technology vendors is taking its time to adapt, but the rationale, the tools, and new players for a cloudified network are here, and some are already starting to use them to their advantage [21].

# References

**[1]** Open Networking Foundation, “CORD”, 2021 [Online]. Available: https://opennetworking.org/cord/

**[2]** O-RAN Alliance, "O-RAN Alliance", 2021 [Online]. Available: https://www.o-ran.org/

**[3]** ITU-T, Y.3150, “High-level technical characteristics of Network Softwarization for IMT-2020", September 2020

**[4]** IBM and 451 Research, “Network Cloudification , 5G and Edge Computing - Strategic Perceptions and Practitioner Views,” pp. 1–16, 2021, [Online]. Available: https://www.ibm.com/search?lang=en&cc=us&q=Network%20Cloudification%20%2C%205G%20and%20Edge%20Computing%20-%20Strategic%20Perceptions%20and%20Practitioner%20Views

**[5]** Open Networking Foundation, TR-521, “SDN Architecture 1.1", February 2016

**[6]** ETSI, "Network Functions Virtualization (NFV)", 2021 [Online]. Available: https://www.etsi.org/technologies/nfv

**[7]** 3GPP, TS 23.501, ” System Architecture for the 5G System; Stage 2; V16.10.0”, September 2021

**[8]** Broadband Forum, TR-384, “Cloud Central Office Reference Architectural Framework”, Issue 1, January 2018

**[9]** Red-Hat, "What is service-oriented architecture (SOA)?", 2021 [Online]. Available: https://www.redhat.com/en/topics/cloud-native-apps/what-is-service-oriented-architecture

**[10]** Metaswitch, "The Service Communication proxy 5g caught up in a service mesh", 2021, [Online]. Available: https://www.metaswitch.com/blog/the-service-communication-proxy-5g-caught-up-in-a-service-mesh

**[11]** MetaSwitch, "Accelerating the NFV data plane", 2021 [Online]. Available: https://www.metaswitch.com/blog/accelerating-the-nfv-data-plane

**[12]** Microsoft, "Overview of single root i/o virtualization", 2021 [Online]. Available: https://docs.microsoft.com/en-us/windows-hardware/drivers/network/overview-of-single-root-i-o-virtualization--sr-iov-

**[13]** Selectel, "Introduction to DPDK Architecture Principles", 2021 [Online]. Available: https://blog.selectel.com/introduction-dpdk-architecture-principles/

**[14]** ebpf.io, "eBPF", 2021 [Online]. Available: https://ebpf.io/

**[15]** Linux Networking Documentation, "AF_XDP", 2021 [Online]. Available: https://01.org/linuxgraphics/gfx-docs/drm/networking/af_xdp.html

**[16]** Fd.io, "The universal dataplane", 2021, [Online]. Available: https://fd.io/

**[17]** TechTarget, "An introduction to smart NICs and their benefits", 2019 [Online]. Available: https://www.techtarget.com/searchnetworking/tip/An-introduction-to-smart-NICs-and-their-benefits

**[18]** P4 Working Group, "The P4 Open-Source Programming Language", 2021, [Online]. Available: https://p4.org/

**[19]** A. Brízido, G. Gaspar, M. Santos, R. Calé and V. Mirones, “Redesigning the network edge for a new era,” InnovAction #5, vol. 1, no. 5, pp. 103–115, 2020

**[20]** Broadband Forum, TR-459, “Control and User Plane Separation for a disaggregated BNG", Issue 1, June 2020

**[21]** Joanne Taaffe, TM Forum Inform, "Networks follow OSS/BSS into the public cloud", 2021 [Online]. Available: https://inform.tmforum.org/insights/2021/06/networks-follow-oss-bss-into-the-cloud/

# 07 Heading to a successful private digital convergence

**Francisco Fontes, Altice Labs**
fontes@alticelabs.com

**Miguel Freitas, Altice Labs**
miguel-r-freitas@alticelabs.com

**Rui Calé, Altice Labs**
cale@alticelabs.com

With the advent of 5G, private cellular networks are on the hype. 5G has emerged as a multi-connectivity technology, being the right enabler for the digital transformation industries need to embrace. Past experience tells us that there is no single technology to serve all scenarios best and fulfill requirements. A successful strategy must be based on a broader vision, integrating diverse wireless and wired technologies while looking into the private domain as part of a bigger ecosystem. It should also account for high-level operational tools that allow customers to focus on their data, processes, and business. Such vision integrates 5G, WLAN, optical technologies, and data collecting and processing in a multi-site and multi-cloud environment under a common control and management layer.

## Keywords

5G; Private networks; Convergence

# Introduction

Enterprises must be efficient and agile to survive in a challenging global market. To achieve this purpose, digitalization in all the production steps and processes is unquestionable, with the integration of intelligence, automation, and computation-based tasks. Process digitalization requires distributed computation and, inherently, suitable communication channels to interconnect all the involved components. Sensors, actuators, automated guided vehicle (AGV), displays, video cameras, or computers each have their own specific connectivity capabilities, requirements, and context. Data storage and processing have also to adhere to requirements and policies, fulfilled by a scalable and continuum of computational resources, ranging from the local infrastructure to public clouds. Thus, the deployment of local, suitable communication infrastructures is of paramount relevance for the enterprise that wants to grow and succeed.

Current private networks are generally based on legacy wired or wireless (WLAN) Ethernet . More demanding production processes require specific communications, enhanced security, and reliability, like time-sensitive networks (TSN), which define mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks. 5G is targeted to fulfill Industry 4.0 needs for wireless connectivity on the factory floor, guaranteeing security, minimum delay, deterministic response, and high reliability.

Private cellular networks are not new, but, as shown in **Figure 1**, from a current estimate of about one thousand private networks based on 3rd Generation Partnership Project (3GPP) specified technology, their numbers are expected to grow to 10's of thousands due to:

- Guaranteed local coverage, enabled by the availability of localized private, unlicensed/shared spectrum and cost-efficient, cloud-based 4G/5G core deployments;
- Reduced total cost of ownership (TCO) from the elimination of wired and other connectivity (e.g., Wi-Fi);
- Growing demand for enterprise information and data security, associated with localized data processing capabilities for ultra-high-performance applications;
- Search for increased productivity solutions through automation and digitalization of enterprise processes;
- Demand for low latency and reliable services.

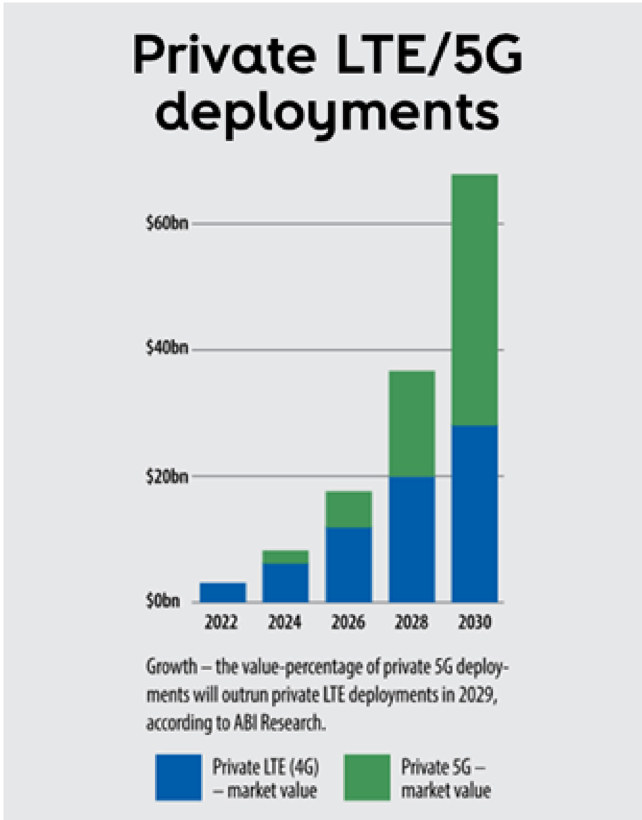


**FIGURE 1** – Expected growth of private cellular networks (LTE and 5G) [4]

Polaris Market Research predicts that the global 5G private network market will grow at a CAGR of 40.9% between 2020 and 2028 [1]. ABI Research forecasts that it could be worth US$16.3 billion by 2025, in line with **Figure 2**. Nokia's CEO Pekka Lundmark recently commented that more money

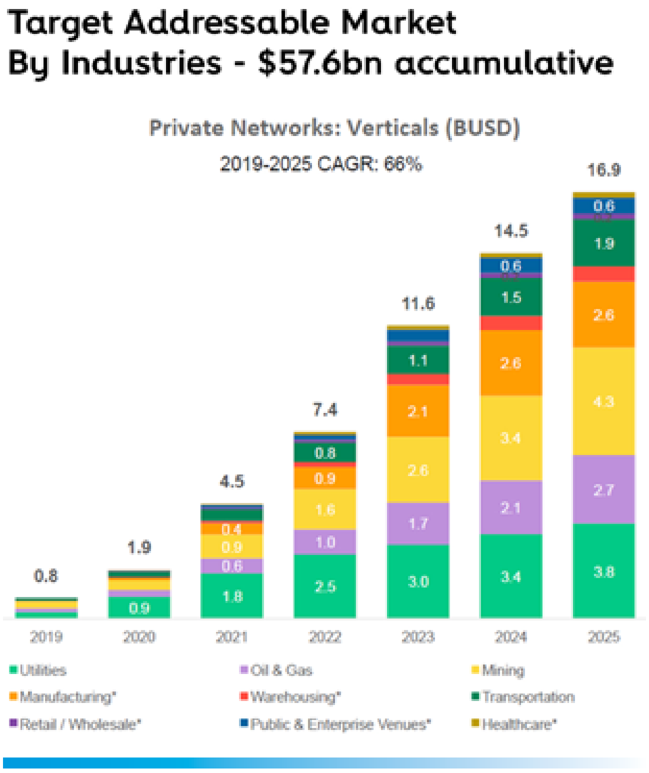


**FIGURE 2** – Expected evolution of the private market value by vertical [6]

will be invested in private 5G networks than in public networks over the next ten years [2], significantly fostering their growth.

However, the widespread adoption of private 5G networks will only become a reality when their operational costs become small, and a seamless interworking between 5G access and other industry technologies, like wired Ethernet or Wi-Fi, is achieved [3]. Taking advantage of a 5G network and its associated services via a non-3GPP access opens the opportunity for new value-added services to be extended to a larger group of devices and use cases. Altice Labs is working on the development of wireline-wireless integrated connectivity and computing solutions for private industrial domains, to guarantee the best possible continuous connectivity for all scenarios. This article extends the concept to all technologies while keeping common control and management, bringing fixed-mobile convergenc to the private domain.

# Private 5G networks

In the technical specification related with service requirements for the 5G system [5], 3GPP describes non-public networks (NPN), 3GPP's terminology for private networks, as being "*intended for the sole use of a private entity such as an enterprise, and may be deployed in a variety of configurations, utilizing both virtual and physical elements. Specifically, they may be deployed as completely standalone networks, they may be hosted by a public land mobile network (PLMN), or they may be offered as a slice of a PLMN*". That way, a 5G NPN consists in the usage of a 5G system for private use, being deployed as:

- a standalone NPN (SNPN): operated by an NPN operator and not relying on network functions provided by a PLMN, or
- a public network-integrated NPN (PNI-NPN): a non-public network deployed with the support of a PLMN.

As any 5G system, 5G NPN are composed of user equipments (UE) - terminals or end-systems -, 5G accesses - consisting of next-generation NodeB (gNB) units connecting UE via a 5G new radio (5G-NR) wireless interface -, and a 5G core (5GC). Hence, SNPN and PNI-NPN use the same underlying network solutions, including hardware and software, the same encoding schemes, and the same type of spectrum as public 5G networks. However, they differ in their usage. While a public 5G network is intended for public usage, with tens of millions of subscribers on a given nationwide network, typically supporting best-effort applications, a private 5G network is dedicated to a single enterprise or organization. Often, they are confined to a single location, which can be as small as a building or as large as a sea or airport, supporting more demanding applications (e.g., remote control of a machine). This impacts, for instance, dimensioning and redundancy of the different control and data plane entities, the adopted security and authentication mechanisms, and the distribution of the available bandwidth in the up and downlink directions. Besides the two extreme SNPN and PNI-NPN scenarios, other intermediate solutions are possible, for instance, via RAN sharing between the operator and private entities, as is the case of a multi-operator core network (MOCN).

In a phased approach, a private entity may start by a PNI-NPN for the initial, less demanding use cases and progress towards an SNPN, as the technology matures, gets cheaper and a higher level of digitalization is achieved, leading to more demanding use cases, requiring dedicated 5G support (as shown in **Figure 3**).

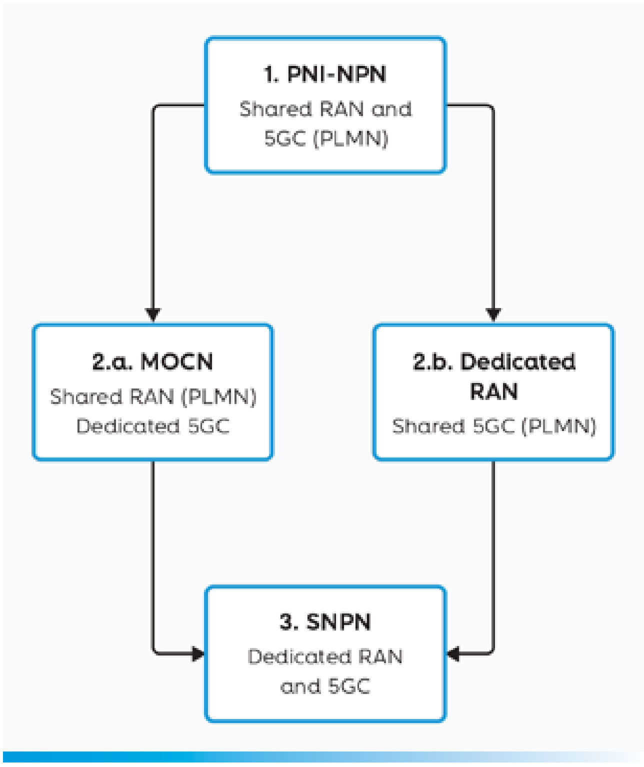


**FIGURE 3** – Possible NPN deployment evolution for a single enterprise

For each of the identified deployment options, we have the following:

**1. PNI-NPN**

- The NPN is established on top of the PLMN via slicing, a differentiating feature of 5G;
- Private 5G data is delivered at the operator domain. Via an existing or new connection, most likely protected by a virtual private network (VPN), the traffic will be exchanged with the private domain;
- The operator may deploy dedicated regional 5GC to address the B2B market, independent from public, B2C services. Still and to a large extent, common core and RAN configurations are shared between different business customers.

**2.a. MOCN**

- To benefit from specific configurations and UE provisioning, business customers may deploy their own 5GC at their premises but share a common 5G access;
- This 5GC may already be used to control/manage other accesses;
- Common RAN configurations will be shared amongst customers, and traffic is delivered at a common point, even if securely isolated from others;
- Considering the availability of open source 5GC implementations, this may represent a CAPEX suitable to start with for most enterprises.

**2.b. Dedicated RAN**

- A dedicated RAN and user plane function (UPF) is locally deployed, guaranteeing the date plane is restricted to the enterprise premises, which can be configured according to specific customer needs;
- A shared 5GC exists at the operator domain, which shall be multi-tenant;
- Having local and possibly shared core UPF units, convergence, traffic steering, and multi-connectivity is likely to be possible;
- It requires spectrum (dedicated, sub-leased from the operator, shared, or unlicensed) to be dedicated for this private usage.

### 3. SNPN

- A complete 5G system is deployed at the enterprise with dedicated RAN and other access components (convergence);
- Like the previous one, it requires a dedicated 5G spectrum;
- It provides maximum control over the data and control planes but shall also be the more expensive solution in CAPEX and OPEX.

Starting with the PNI-NPN model may be impossible since just a few operators have deployed 5G in standalone mode. Most operators are focusing their current investments in non-standalone mode, by upgrading their evolved packet core (EPC) nodes and adding 5G radios on selected cell sites to address the consumer market with more bandwidth. Regarding MOCN, the required RAN sharing implies customers are in the same coverage area, and cell locations will most likely be outdoors.

Altice Labs is working on solutions where the radio access (5G-NR) is always deployed at the private domain as dedicated access. **Figure 4** illustrates three possible configurations, with the first corresponding to the SNPN scenario described above, with middle and right ones as variations of the dedicated RAN scenario. Here, the focus is on the location of the control entities and edge computing platforms.

The first deployment enables maximum security with minimum delays. Still, via its external access, workloads can be placed at the operator edge or central (and public) clouds. In the second situation, the multi-tenant shared control plane is located at the operator domain, most likely at the edge, reducing CAPEX and OPEX. With a local UPF and convergence units, data processing can be done locally or at the operator's edge, possibly under 5G traffic steering control. The third situation is the one with fewer costs for the enterprise. Only the minimum required infrastructure is locally deployed to ensure local accesses, with all the computational processing delegated to the operator or Internet domains.

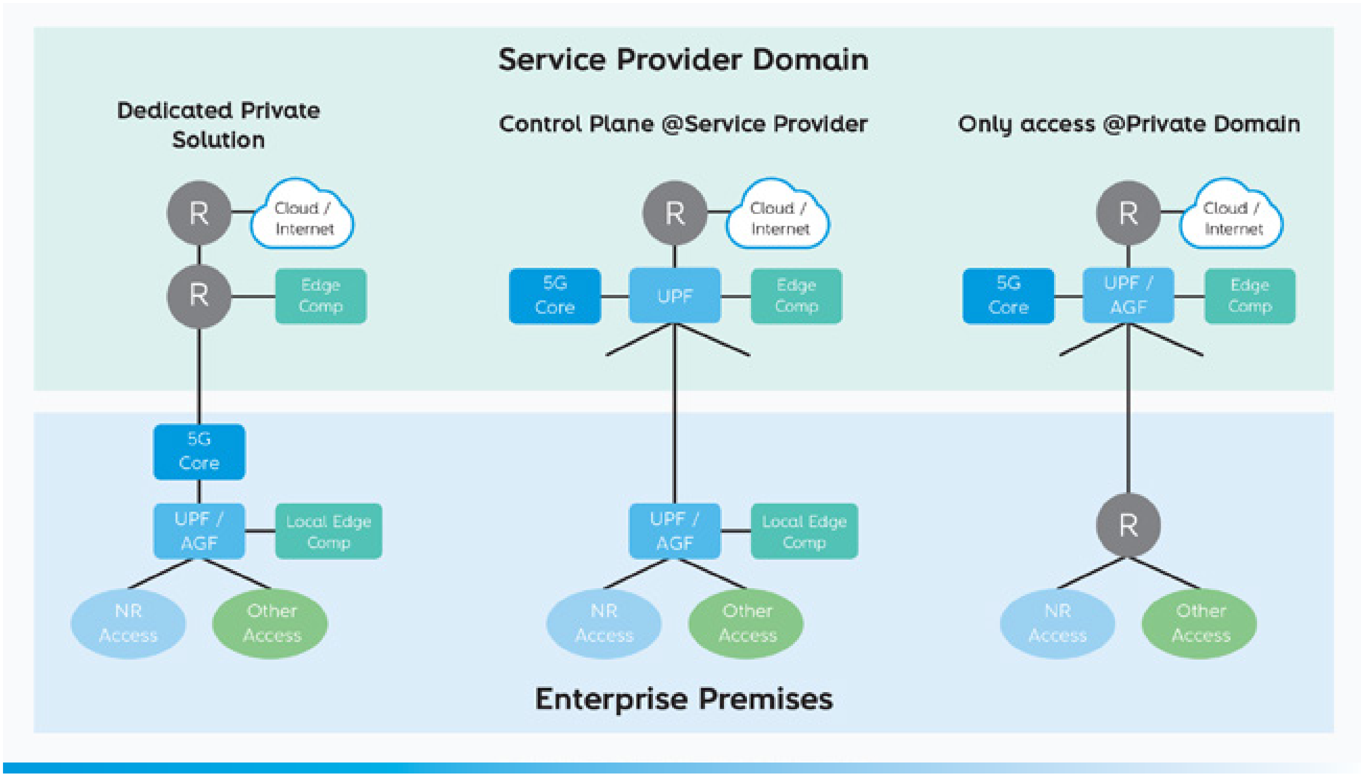


**FIGURE 4** – Different NPN deployment configurations, distributed between public and private domains

# Convergence and 5G

5G may not be the best connectivity solution for all use cases, even if technically feasible. Considering the different connectivity requirements, other wireless (e.g., WLAN) and wired (copper or fiber) technologies may, currently, be more cost-effective and less complex for some of the use cases and, most likely, be already deployed. Considering 5G characteristics, it shall be adopted in demanding ultra-reliable and low-latency communications (URLLC) use cases, providing connectivity in specific functional and geographic areas. With convergence, private industrial networking continues being a heterogeneous environment, but with common management and operation of all accesses as a single network, via a common 5G control plane and traffic aggregation entities. The 5GC control and data planes have the capability to serve other access technologies. In the scope of private deployments, potential 5GC shared services include:

- Common and consistent authentication/registration and global assignment of security policies;
- Unique IP address management;
- Consistent traffic management (e.g., routing, forwarding, inspection, policy enforcement, QoS handling, and reporting) across all access types;
- Transversal slicing/virtual networking management;
- Exposure to external entities as a single network.

Additionally, convergence enables multi-technology endpoints to choose the access technology to use at each time (traffic steering and switching) and even to connect simultaneously via different access technologies (traffic splitting). Starting with multi-radio dual connectivity (MR-DC) in Release 15, this is now specified as access traffic steering, switching and splitting (ATSSS), currently part of 5G standards.

Fixed-mobile convergence (FMC) or, more recently, wireline-wireless convergence (WWC) has long been addressed by 3GPP [7] and other organizations like the Broadband Forum [8], defining solutions for a shared common mobile core, serving wired and wireless access technologies. Already addressed in 4G/LTE scope, this gained higher relevance with 5G due to its intended broader scope.

Convergence in 5G is achieved at the core via functional entities placed at the 5G domain entrance, which adapt access specific protocols to standard N2 interface control plane (CP) and N3 interface data plane (DP). The N1 interface, used to convey non-radio signaling between the UE and the 5GC, may not be supported by

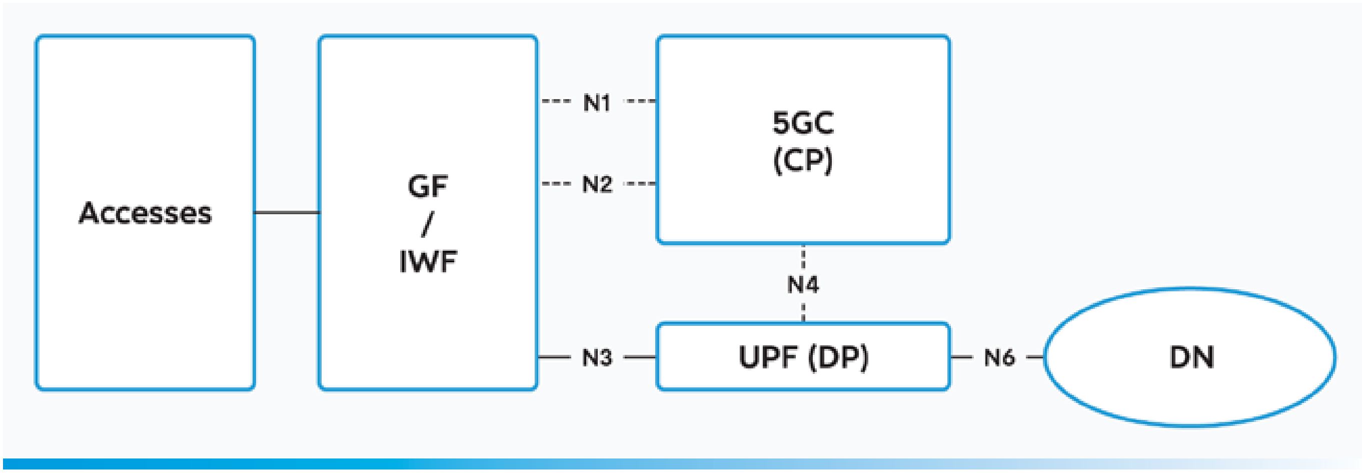


**FIGURE 5** – Access networks integration with a 5GC

the terminal equipment, forcing the adaptation entities to handle it on behalf of the terminal (as shown in **Figure 5**). That is the case for most of the residential gateways and WLAN-only devices.

Security mechanisms for authentication and data encryption are key aspects in convergence since they must be present whenever a terminal attaches to the network. However, they are deeply dependent on the nature of the used access network. A unified authentication framework was defined for 5G, where 5G authentication and key agreement (5G-AKA) and extensible authentication protocol (EAP) for the 3rd generation authentication and key agreement (EAP-AKA') are mandatory 5G primary authentication methods. That framework makes 5G-AKA procedure suitable for both open and access-network agnostic scenarios, relying on three authentication methods: 5G-AKA, EAP-AKA', and EAP transport layer security (EAP-TLS). The framework enables the existence of multiple security contexts that can be established with a single authentication execution, allowing the UE to move from a 3GPP access network to a non-3GPP network without having to be unauthenticated [9].

Different adaptation entities were, so far, defined, mainly differentiating on security aspects. Besides gNB and next-generation e-NodeB (ng-eNB), for native 5G-NR and long-term evolution (LTE) accesses, respectively, the following four additional 5G access node types exist (detailed in [10] and [11]):

- Non-3GPP interworking function (N3IWF), which allows 5G capable terminals (supporting non-access stratum - NAS - to connect from untrusted WLAN or other accesses deployed by third-party entities, out of the scope of 5G network owner control;
- Trusted non-3GPP gateway function (TNGF) and trusted WLAN interworking function (TWIF), aimed for trusted non-3GPP and WLAN accesses, but requiring the UE to have 3GPP credentials and, for the first case, to support NAS. They are based on the tight coupling between a trusted access point and a gateway or interworking function;
- Wireline access gateway function (W-AGF), which connects a wireline 5G access network (W-5GAN) to the 5GC network. It is similar to the TNGF for 5G residential gateways (5G-RG) and the TWIF for fixed-network residential gateways (FN-RG) but considering the specific characteristics of fixed access networks. 5G-RG units support NAS signaling and authenticate themselves, while FN-RG do not support 5G capabilities and do not have 3GPP credentials in this specific context.

From the previous, it can be observed the lack of standards to support pure WLAN devices connections to the 5GC. This is identified in the 5G work group [10] by the Wireless Broadband Alliance (WBF), stating that "*most Wi-Fi-only devices, e.g., devices in enterprise deployments, would not have a USIM included,*" recommending that "*3GPP needs to define architecture and procedures for supporting Wi-Fi only UE with non-IMSI based identity and EAP-TLS/EAP-TTLS based authentication*". Altice Labs is aware of this limitation and is working towards an interim, proprietary solution, while this is not addressed by 3GPP.

# Traffic steering

Depending on the context, terminals located at the private domain need to, transparently and dynamically, be served at the same premises, on the operator edge, or at central clouds. 5G has built-in mechanisms for dynamic traffic steering via API exposed to service platforms or applications functions (AF).

Via the network exposure function (NEF) (using reference point N33 for untrusted services) or directly via the policy control function (PCF) (using reference point N5 for trusted platforms), services may dynamically change the anchor point, or protocol data unit (PDU) session anchor point (PSA) on the network side of running 5G PDU sessions, switching between different UPF instances, and thus providing access to different service platforms (depicted in **Figure 6**). This is particularly interesting for moving terminals (e.g., a change in gNB/centralized unit may trigger a change in the anchoring UPF to keep latency low) or in the scope of edge computing (e.g., to serve users at the right 'distance' for their changing latency requirements, or under periods of network congestion). Despite limited applicability for SNPN, with a small number of UPF in a limited geographical area, it may become crucial for shared 5G control scenarios in which traffic is steered between local and edge data centers (see the middle scenario depicted in previous **Figure 4**).

Altice Labs has demonstrated this functionally [12] by integrating Intel® Smart Edge Open distribution [13] (via OpenNESS AF) with the PCF of Fraunhofer FOKUS' Open5GCore [14].

# Multi-connectivity

The ability to attach multiple access technologies to a 5GC provides significant flexibility in the planning and operation of network environments. Although the physical areas covered by the different access networks may be complementary or overlap, providing the network and terminals with simultaneous multi-connectivity directly promotes that flexibility.

3GPP Release-16 5G specifications include the ATSSS functionality. Steering refers to the capacity to select the best link to use for the data plane traffic, according to the service (QoS type for a data flow). Switching allows data plane traffic to switch to another access technology without service interruption. Splitting means the simultaneous use (bonding) of several network connections (PDU sessions). As an example, leveraging simultaneous

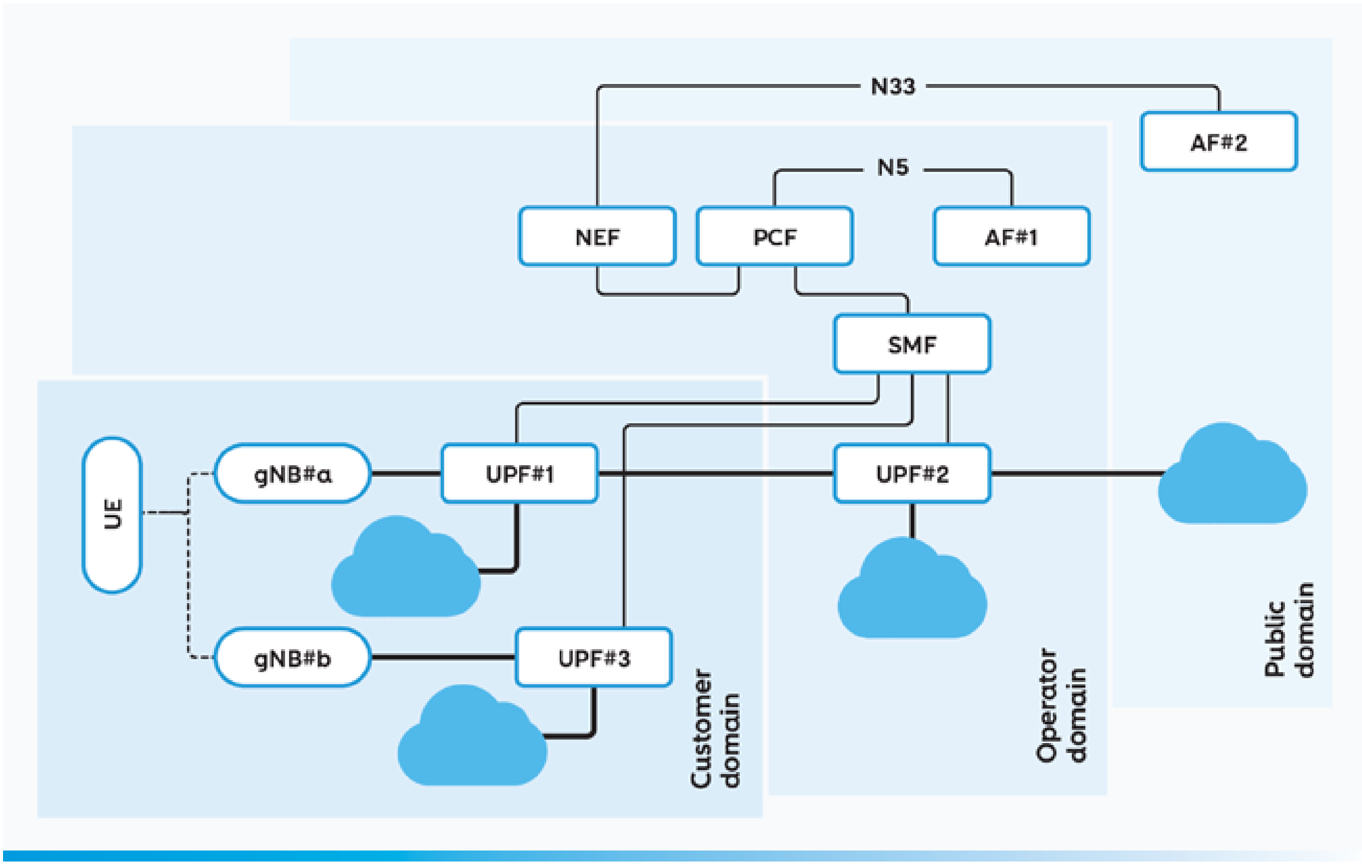


**FIGURE 6** – Traffic steering control scenarios, for trusted and untrusted application functions

communication over multiple paths (typically over one 3GPP access and one non-3GPP access) gives 5G systems the mechanisms to provide services with improved user experience, distribute traffic across multiple accesses in a policy-based fashion, and enable new high-data-rate services.

In the 5GC, the ATSSS functionality will be co-located with the UPF, making it a "UPF+ATSSS" node (as depicted in the 'b' option of **Figure 7**). While 5G systems do not natively integrate the ATSSS functionality (to be part of 3GPP Release-17 specifications), this can be enabled by placing the ATSSS gateway in complement to an existing UPF (shown as the 'a' option in **Figure 7**). ATSSS-enabled terminals will still be able to steer, switch or split traffic between two or more accesses, based on rules and information received from the network.

To take benefit of the ATSSS features, the IP transport layer has to adapt to the new multipath environment. As such, multipath transmission control protocol (MP-TCP) [15] was adopted by 3GPP in Release-16 as the solution for ATSSS. However, it only applies to TCP traffic. IETF's Transport Area Working Group (TSVWG) [16] is working in multipath-datagram congestion control protocol (MP-DCCP) to make it a suitable ATSSS alternative to multipath quick UDP Internet connections (MP-QUIC) [17] for IP and UDP traffic, and be adopted in 3GPP Release-18.

With the purpose of having complete and efficient ATSSS solutions in the market for its convergent private network solution, Altice Labs is actively supporting the development and adoption of MP-DCCP as an ATSSS technology in 3GPP Release-18 specifications. Equipped with such functionality, the Altice Labs' solution is ready to always provide the best connectivity.

# Conclusions

Exploiting specific technology characteristics, private 5G networks are on the rise, with commercial deployments in more advanced markets but still with a strong experimentation objective. They will only achieve significant numbers in 2024 (as shown in previous **Figure 2**) mainly because they are complex, require specific skills to plan, deploy and maintain, and are still an expensive technology, especially in the RAN.

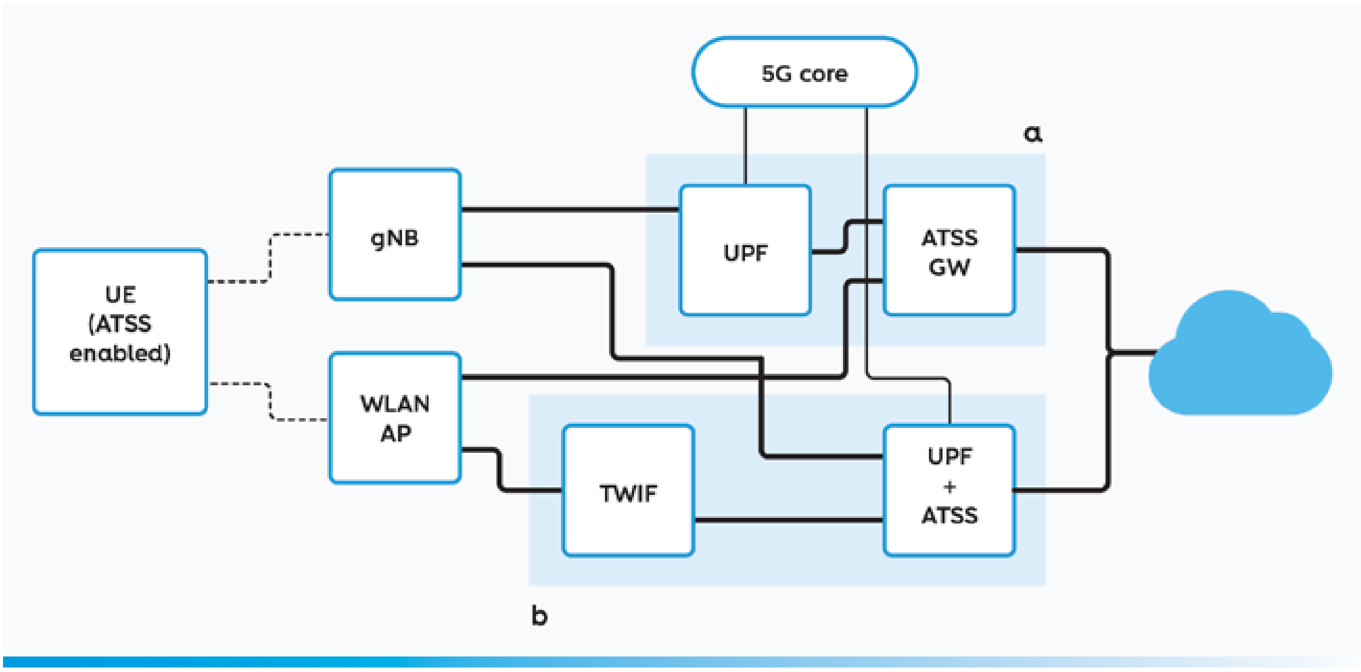


**FIGURE 7** – Possible ATSSS implementations

This is expected to change with OpenRAN based solutions, like the Altice Labs' solution. Until then, relevant industry features in 3GPP Release-16 specifications but especially with Release-17 and following ones are not yet implemented in commonly available 5G solutions. Other components to share the control and data planes, reducing customers CAPEX and OPEX, are not yet mature to be considered in the near future.

Still, Altice Labs is building a convergent solution for private networks based on a selected 5GC and integrating its own 5G-NR technology, composed of centralized, distributed, and radio units (CU, DU, and RU), aligned with the OpenRAN architecture. Such convergent solution is presented next, in the article "Enabling 5G private mobile networks". This complete 5G system, with the addition of gateway and interworking functions, integrates WLAN and xPON, this last one as an access technology (private optical LAN) and as the midhaul for the 5G-NR cells, also based in Altice Labs' technology. Except for RU, optical network unit (ONU), and optical line termination (OLT) components, all run as virtualized software elements, operated as containers in a suitable clustered platform.

The proposed solution integrates the features referenced throughout this article:

- Converged wireline and wireless accesses over the same 5GC;
- Network traffic steering to access services transparently at the edge, at the core or in public clouds;
- Traffic steering, switching, and splitting over different accesses;
- Integration with edge computing;
- Cloudification of all its software components.

The following **Figure 8** provides a high-level representation of the overall solution.

In order to have a complete and flexible solution, answering the requirements of customers of all dimensions and from all geographies, other areas, like multi-site private networks, integration and interoperation of private and public networks, or multi-tenant control sharing from the edge, to mention only the most relevant, will be addressed in the near future.

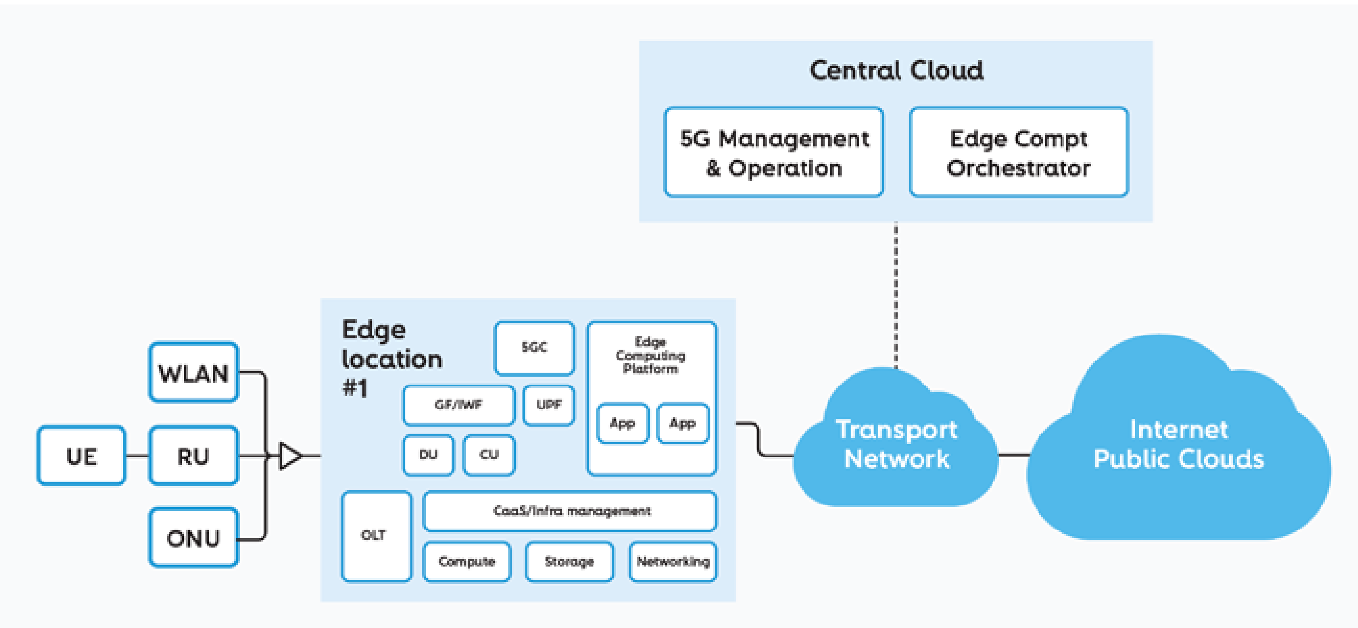


**FIGURE 8** – Global view of current Altice Labs' solution for convergent private networks

# References


[1] Polaris Market Research, "Private 5G Network Market Share, Size, Trends," Polaris Market Research, NYC, 2021

[2] D. Manners, "Eletronics Weekly.com," Eletronics Weekly.com, 24 February 2021. [Online]. Available: https://www.electronicsweekly.com/news/business/private-network-5g-pending-outpace-public-network-spending-says-nokia-ceo-2021-02/

[3] H2020 5G Clarity, "5G-CLARITY Deliverable D2.2 - Primary System Architecture," 5G PPP, 2020

[4] Enterprise IoT Insights, "Private 5G Enterprise NOCs - Where and how will mobile operators manage private 5G enterprise networks?," RCR Wireless News, 2021

[5] 3GPP, "Service requirements for the 5G system - TS 22.261," 3GPP Portal, 2017

[6] 5G Americas, "5G Technologies in Private Networks," 5G Americas, USA, 2020

[7] 3GPP, "Wireless and wireline convergence access support for the 5G System (5GS) - TS 23.316," 3GPP Portal, 2019

[8] Broadband Forum, "TR-470: 5G Wireless Wireline Convergence Architecture," Broadband Forum, 2020

[9] TechPlayOn, "5G Authentication and Key Management 5G-AKA," TechPlayOn, 26 March 2021. [Online]. Available: https://www.techplayon.com/5g-authentication-and-key-management-aka-procedure/

[10] WBA 5G Work Group, "5G and Wi-Fi RAN Convergence - Aligning the Industry on Opportunities and Challenges," Wireless Broadband Alliance, 2021

[11] Broadband Forum, "TR-456: AGF Functional Requirements," Broadband Forum, 2020

[12] 5G-VINNI Consortium, "5G-Vinni," 5G PPP, 2019. [Online]. Available: https://www.5g-vinni.eu/

[13] Intel Corporation, "Intel® Smart Edge Open - Streamline networking and application depoloyment at the edge," Intel Corporation, 2021. [Online]. Available: https://www.intel.com/content/www/us/en/developer/tools/smart-edge-open/overview.html

[14] Open 5G Core, "Open 5G Core," Open 5G Core, 2021. [Online]. Available: https://www.open5gcore.org/

[15] Internet Engineering Task Force (IETF), "TCP Extensions for Multipath Operation with Multiple Addresses," Internet Engineering Task Force (IETF), 2014. [Online]. Available: https://datatracker.ietf.org/doc/html/rfc6824

[16] Internet Engineering Task Force (IETF), "Transport Area Working Group (TSVWG)," Internet Engineering Task Force (IETF), 2021. [Online]. Available: https://datatracker.ietf.org/wg/tsvwg/about/

[17] UCL - Université Catholique de Louvain, "Multipath QUIC - Website of the Multipath QUIC project," UCL - Université Catholique de Louvain, 2021. [Online]. Available: https://multipath-quic.org/


5G

# 08 Enabling 5G private mobile networks

**Hugo Filipe da Silva Reboredo, Altice Labs**
hugo-f-reboredo@alticelabs.com

**José Salgado, Altice Labs**
jsalgado@alticelabs.com

**Samuel Rocha Madail, Altice Labs**
samuel-r-madail@alticelabs.com

**Victor Marques, Altice Labs**
victor-m-marques@alticelabs.com

**Arnaldo Oliveira, Instituto de Telecomunicações, Aveiro**
asroliveira@av.it.pt

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. Aware of it, 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.

## Keywords

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

# 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.

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);

| | |
|---|---|
| **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]

- 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"

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

**TABLE 2** – Comparison of ITU design goals for 5G services [2]

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.

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**):

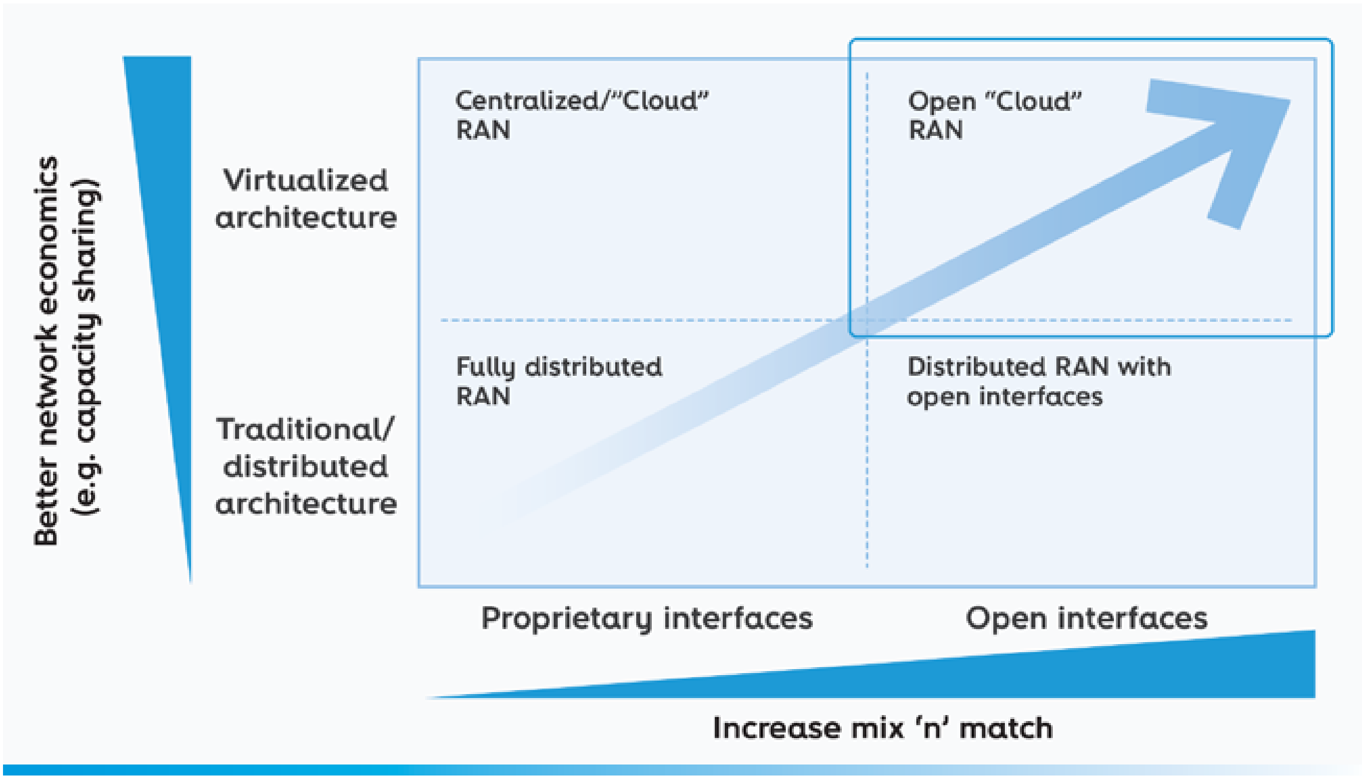


**FIGURE 1** – Interplay between network architecture (traditional or virtualized) and network interfaces (proprietary or open) on RAN type [2]

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

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

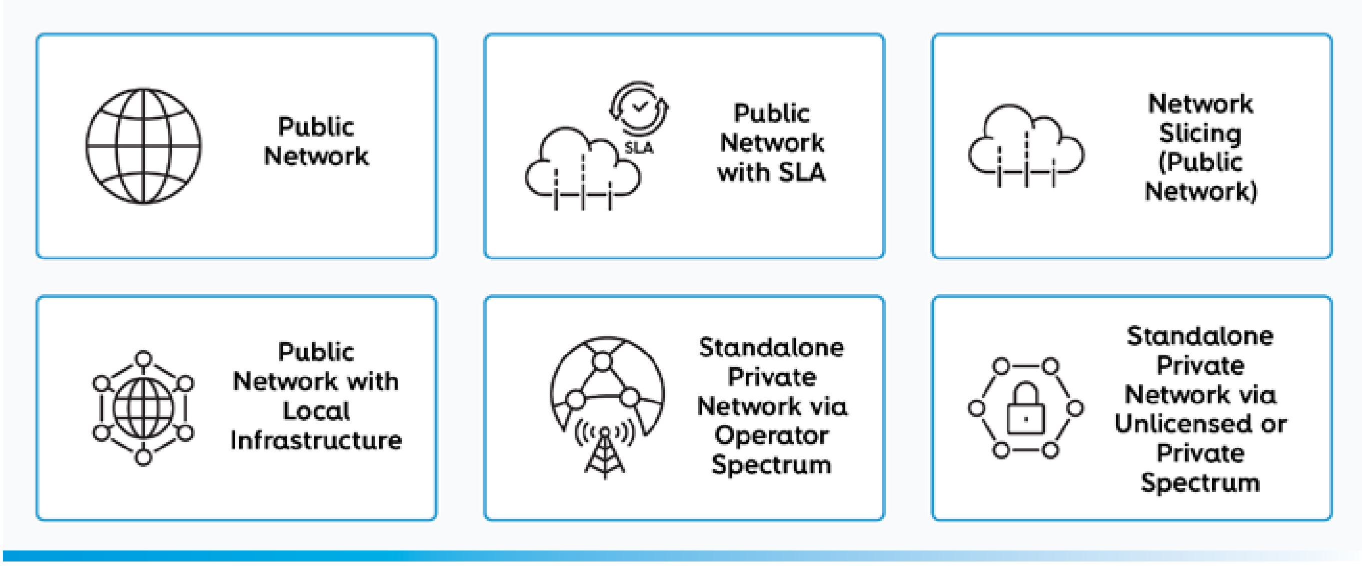


**FIGURE 2** – Range of communication network options for enterprises (public networks to private/dedicated networks) [2]

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.

## 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

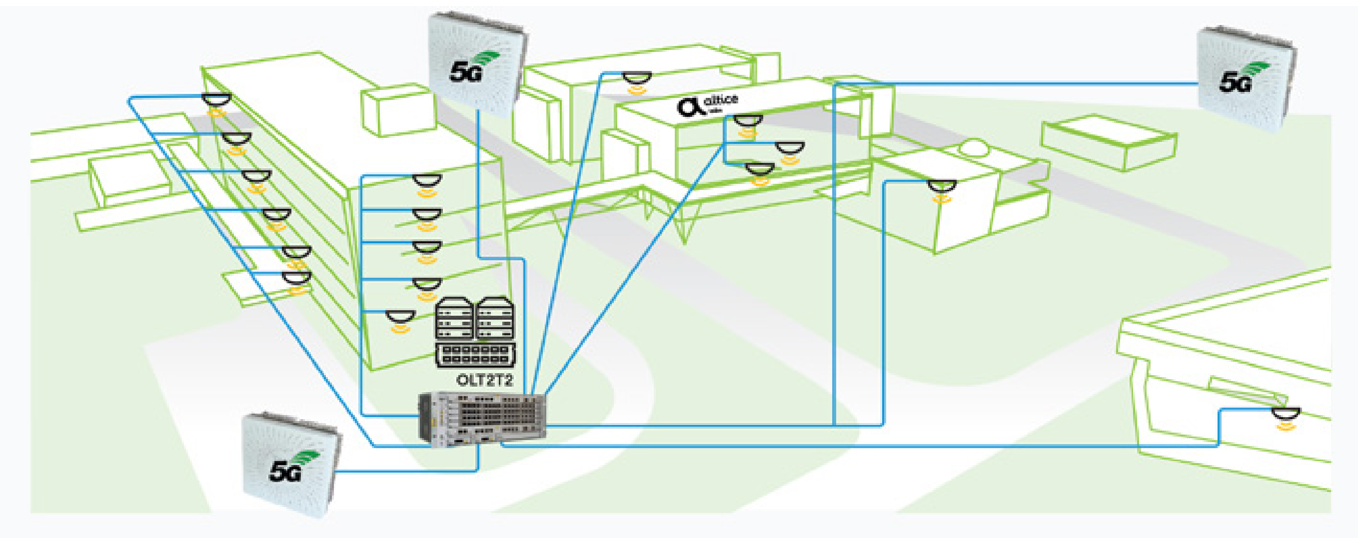


**FIGURE 3** – Geographical distribution of 5G radio units in Altice Labs' campus

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 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.

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;

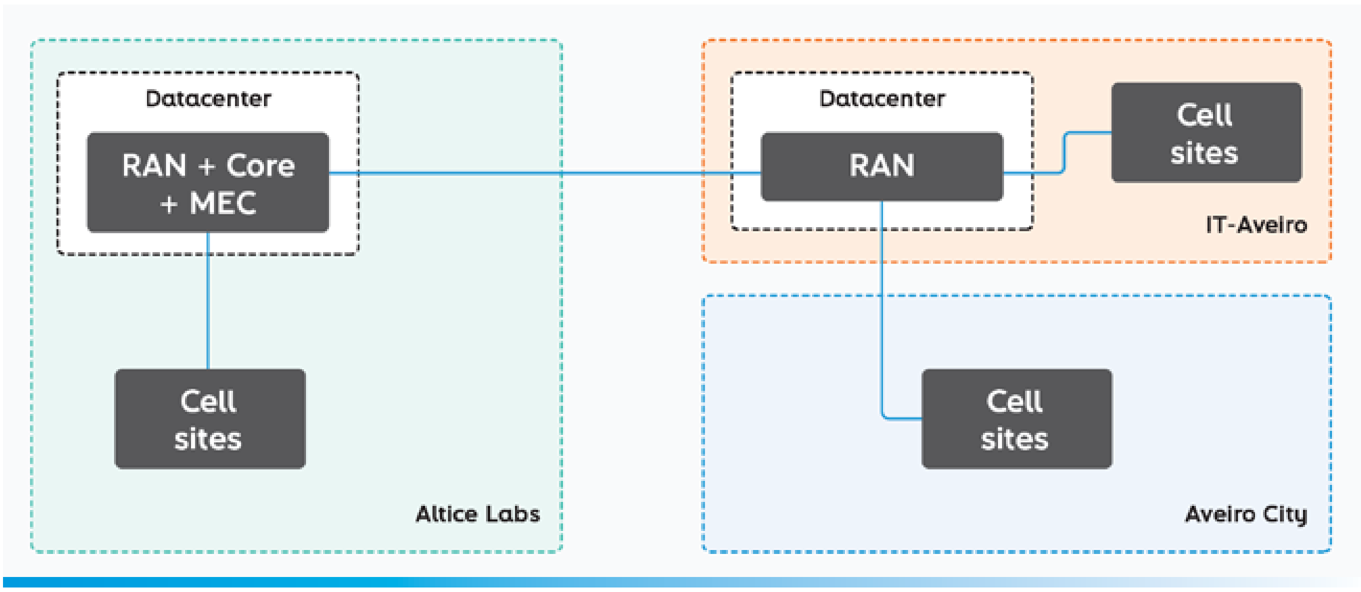


**FIGURE 4** – High-level design of private network

- 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.

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.

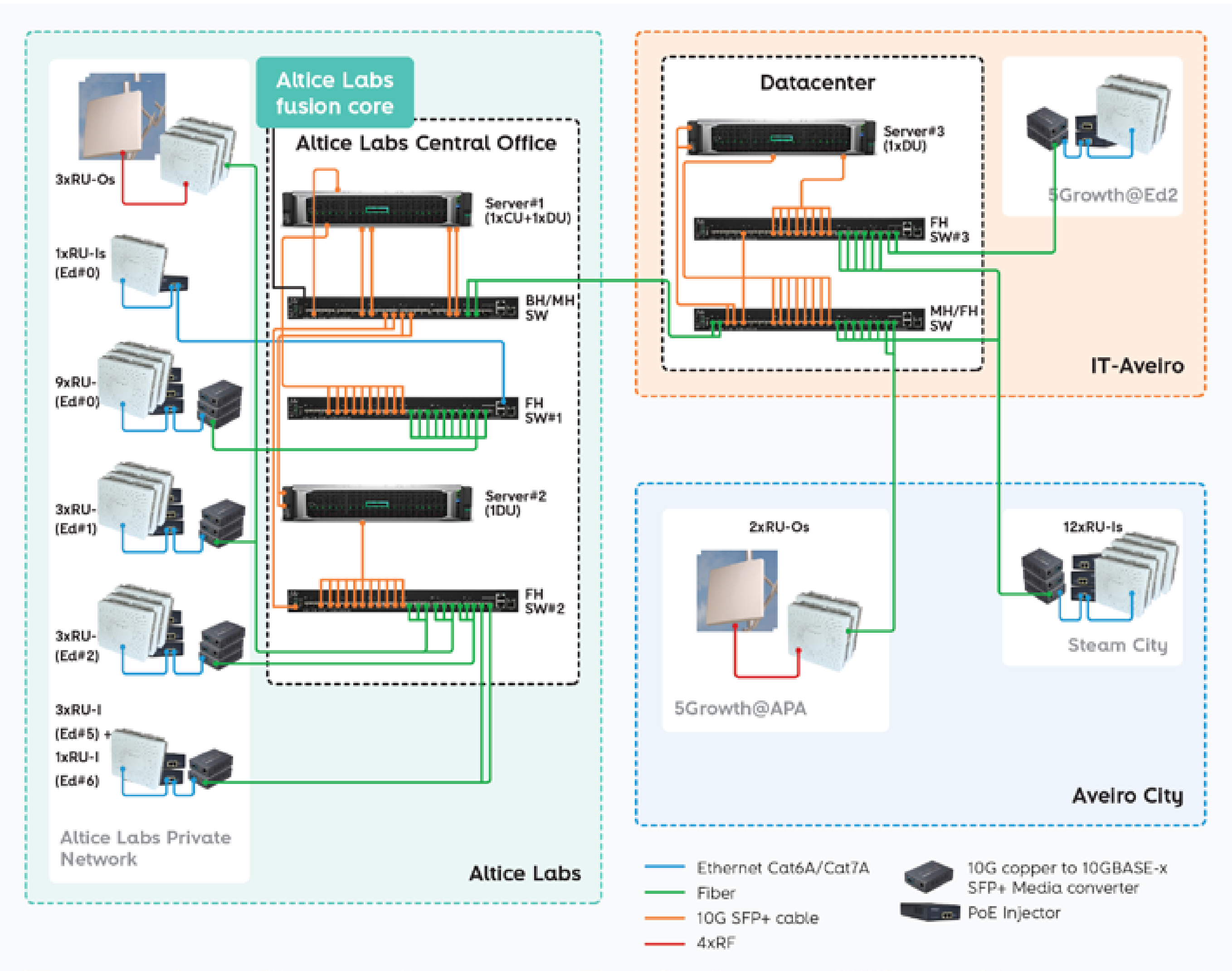


**FIGURE 5** – Detailed design of Altice Labs' private network interconnections

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

# 09 Evolving PON: the future starts today

**Cláudio Emanuel Rodrigues, Altice Labs**
claudio-e-rodrigues@alticelabs.com

**José Salgado, Altice Labs**
jsalgado@alticelabs.com

**Paulo Mão-Cheia, Altice Labs**
maocheia@alticelabs.com

The metamorphosis of PON technologies to support everything from residential services, WiFi, high resiliency services, high bit rate services to RAN applications is notorious.
The access network of the future has to be prepared, which includes serving several segments and different backhaul features. We can conclude that future access networks will be a truly multi-service solution.
Next-generation equipment should be as efficient as possible for allowing minimal energy cost per bit. However, with a minority coalition led by operators and vendors from China preferring a futuristic vision of 50G PON, and a group in favor of initiating the 25G-PON standardization project, the question arises: what will be the next PON technology?

## Keywords

PON technologies; 25GS-PON; HSP-PON; 50G-PON

# Background - GPON, XG-PON and XGS-PON

The gigabit passive optical network (GPON) provides a bandwidth of 2.5Gbit/s downstream and 1.25Gbit/s upstream. The operating wavelength ranges are 1480-1500nm in the downstream direction and 1260-1360nm in the upstream direction on optical network units (ONU) based on Fabry-Perot lasers. The most common optical network units/terminals (ONU/ONT) are based on wavelength-selected lasers and work between 1300 and 1320nm. The 1550-1560nm wavelength range can be used for video distribution.

The standard XG-PON, defined by the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) G.987 series of standards [1], can coexist with GPON and provide 10Gbit/s downstream and 2.5Gbit/s upstream. **Figure 1** depicts the wavelength plan for GPON, XG-PON, and video overlay.

Coexistence between XG-PON and GPON is achieved by implementing a wavelength coupler located at the central office, the wavelength division multiplexer 1 type r (WDM1r). Driven by the 10G optical transceivers market, the Full Service Access Network (FSAN) group selected 1575–1580nm downstream wavelength to promote the technology's maturity. The upstream wavelength was defined at around 1270nm.

For configuration, operation, and maintenance, GPON and XG-PON use the same generic optical network unit management and control interface (OMCI), specified in ITU-T G.988 [2]. ITU-T G.9807.1 standardizes the 10-gigabit-capable symmetric passive optical network (XGS-PON), a system that operates at a nominal data rate of 10Gbit/s in both downstream and upstream directions [3].

One of the great advantages of the XGS-PON system is its coexistence options with GPON and XG-PON using wavelength overlay and/or time-division multiple access (TDMA) methods, i.e., the same XGS-PON optical line termination (OLT) receiver can work on dual-mode and receive XG-PON (2.5Gbit/s) and XGS-PON (10Gbit/s), and, as the downstream wavelength and bitrate are the same as XG-PON, an XGS-PON OLT can control and manage the XG-PON ONT.

Given the major investments spent on time and money on deploying GPON mainly in the fiber infrastructure, the next-generation PON (NG-PON) must be able to protect the investment of the legacy GPON by ensuring seamless and smooth migration capability for subscribers from GPON to NG PON. The most common PON scenario is the brownfield scenario where a PON system has already been deployed, and network operators decide to leverage this existing fiber infrastructure to offer higher bandwidth carrier services using XGS-PON. Subscribers on an existing GPON or XG-PON system might require an upgrade to such higher speed tier service, and the network operator may therefore choose to move over these subscribers to the XGS-PON system while other subscribers remain on the GPON or XG-PON [3] . At a certain point, some network operators may eventually perform a

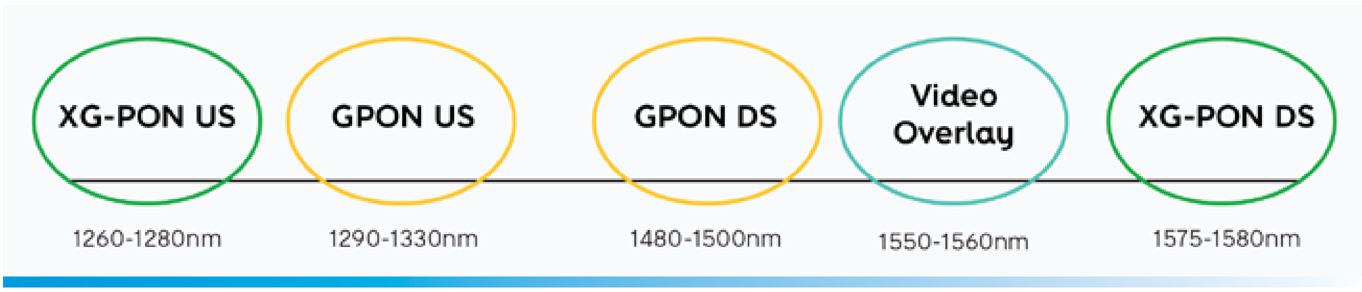


**FIGURE 1** – Wavelength plan for GPON, XG-PON, and video overlay

“forced migration” from GPON to XGS-PON when the number of GPON subscribers becomes low. In this scenario, both GPON and XGS-PON will likely continue to coexist for a relatively long time. In a similar but slightly different migration scenario, a network operator might want to replace an existing GPON with an XGS PON completely. In this case, it would still make sense to run both GPON and XGS PON at the same time and update customers one at a time, but the upgrade window is rather much shorter.

When a PON system is migrated from a legacy PON to an NG-PON, coexistence and smooth migration are important requirements. External WDM1, WDM1r, coexistence elements (CEx and and CEMx) devices provide a good way to support coexistence and smooth migration. However, these external WDM approaches introduce extra insertion loss in the optical distribution network (ODN). Furthermore, it is advantageous for some operators to have an upgrade approach that replaces existing line cards in the OLT chassis with new ones, to upgrade to multiple PON technologies integrated into these line cards. The new line card can simplify the upgrade engineering and reduce the probability of manual operational error during migration [4]. To meet the requirements mentioned above, an OLT line card with an integrated WDM function is introduced. This line card is called an OLT multi-PON module (MPM).

When upgrading using an OLT MPM, no external coexistence element is necessary at the OLT side since its function has been integrated inside the OLT optical module for each PON port. Hence no extra space or associated engineering operations are required to achieve coexistence [4]. To accompany the OLT MPM with an integrated WDM in an upgrade scenario, a TC chipset supporting both legacy PON and NG-PON may be required in the OLT configuration, including specific multi-source agreement (MSA) with dual interfaces to legacy PON and NG-PON [4].

The reference diagram of GPON/XG-PON/XGS-PON OLT MPM with WDM is shown in **Figure 2**. The WDM is used to support all three types of ONU on the same ODN. The GPON transmitter and receiver, XGS-PON transmitter, and dual-rate receiver (also supporting XG-PON ONU) are connected to the internal WDM.

The physical media dependent (PMD) requirements for the optical interface should ensure that the legacy GPON, XG-PON, and XGS-PON ONU can work on the legacy ODN.

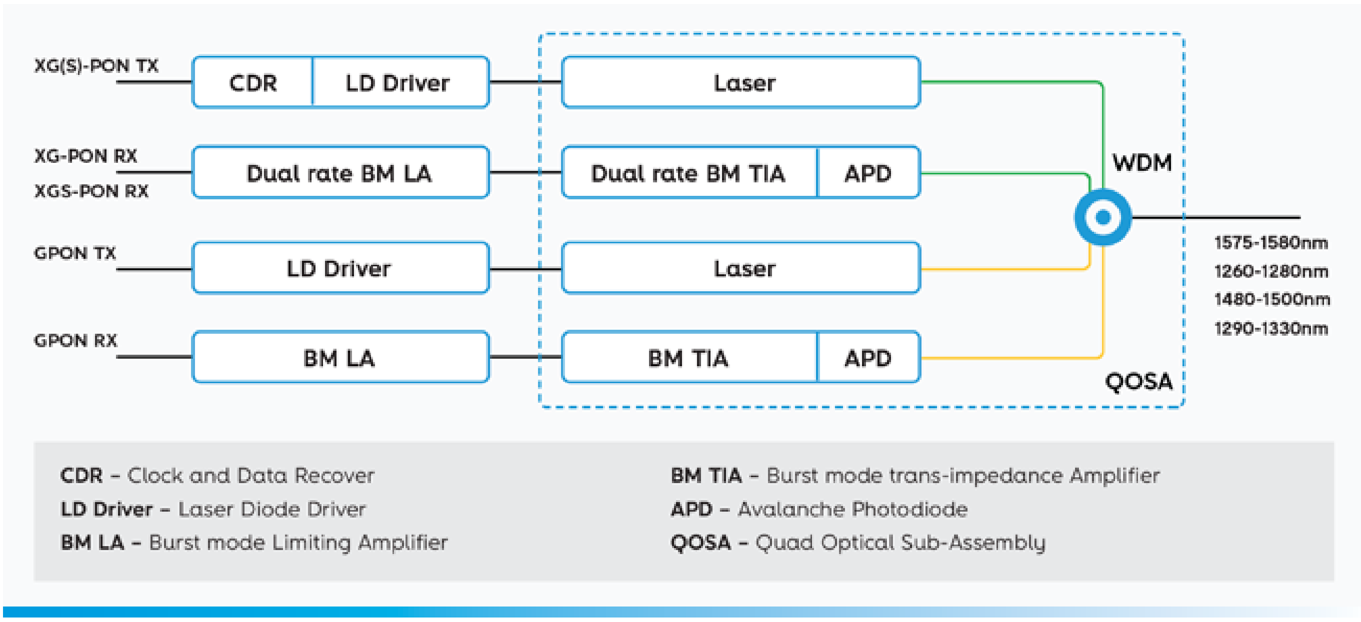


**FIGURE 2** – GPON/XG-PON/XGS-PON OLT MPM with WDM

# NG-PON2

NG-PON2 is a 40Gbit/s capable multi-wavelength PON system that can grow up to 80Gbit/s. It has three types of channel rates: basic rate 10/2.5Gbit/s, and as an option 10/10Gbit/s and 2.5/2.5Gbit/s. ONU are colorless and can tune to any assigned Channel [5] [6] [7] [8].

**Figure 3** depicts the functional optical access network architecture that applies to NG-PON2 systems with legacy systems coexistence. The optical technologies specified for NG-PON2 systems are compatible with legacy power splitting ODN. NG-PON2 systems can also be supported on new (greenfield) ODN that may consist of wavelength filters only, or a combination of both wavelength and power splitters.

By wavelength agility, time wavelength division multiplexing (TWDM) PON allows enhanced network functionalities unavailable in previous generations of pure time division multiplexing (TDM) PON, namely:

- Incremental bandwidth upgrade (pay-as-you-grow);
- Selective OLT port sleep for power saving during low traffic periods, i.e., during times of low traffic load, all ONU can retune to a common wavelength and allow OLT ports to be powered down;
- Resilience against OLT transceiver failures through ONU retuning, i.e., under a fault condition, all ONU can retune to a common standby or working wavelength to maintain a basic service until the fault is cleared;
- Fast, dynamic wavelength and timeslot assignment using dynamic wavelength and bandwidth allocation (DWBA) to improve bandwidth utilization efficiency.

One of the major advantages of TWDM PON is the pay-as-you-grow support, where wavelengths can be added one by one as needed to support customer growth and high-bandwidth applications.

In the case of an existing GPON network, the most likely upgrade approach is to insert a TWDM card into the OLT platform. The TWDM PON line card can have the same wavelength on each port or different wavelengths on the various ports of the line card, depending on the subscriber, application, and bandwidth projections. Several implementations of wavelength mux (WM1) devices are possible, and they can be external to the TWDM card or integrated on it.

**Table 1** provides a comparison from a service availability perspective of the different scenarios.

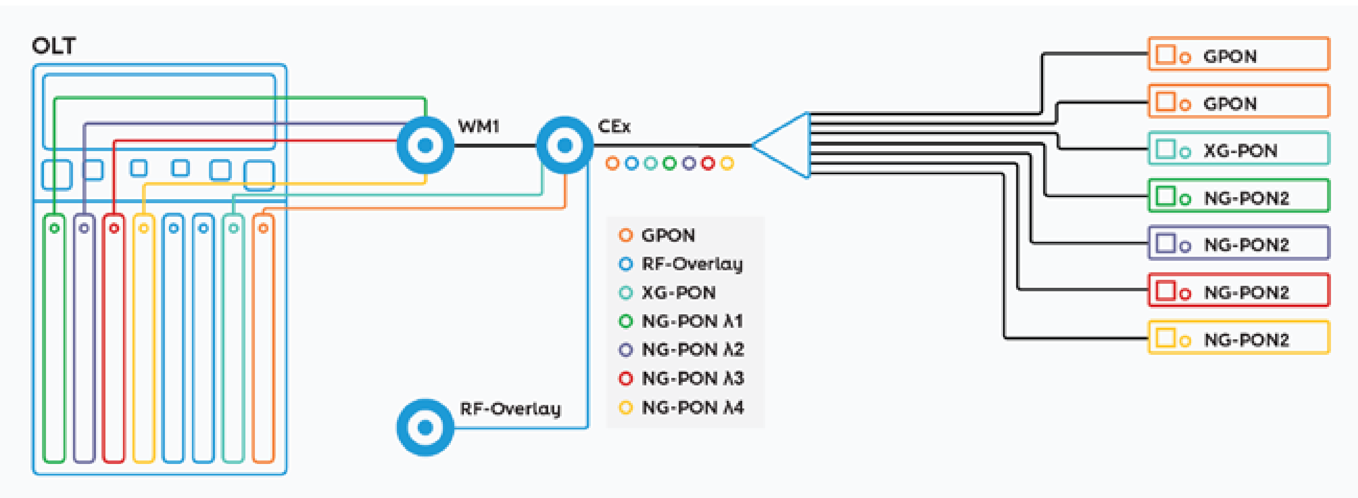


**FIGURE 3** – Functional reference architecture for NG-PON2 system coexistence with legacy systems

| Scenario | Wavelengths on a single card | Wavelengths across cards |
|---|---|---|
| **Wavelength failure** | Affected ONU moved to other wavelength ports of the same card; All ONU are down while the card is rebooting. | Affected ONs moved to other line cards; Other ONU on the card are tuned to other wavelengths before the card reboot. |
| **Complete line card failure** | Affected ONU are down while the card is not replaced. | Affected ONU are moved to other line cards. |
| **Software upgrade** | Affected ONU are down during reboot and reactivation. | Affected ONU are tuned in advance of upgrade. |

**TABLE 1** – Service availability on TWDM-PON

The nonintegrated, modular approach provides several operational and economic advantages, such as:

- Straightforward support for pay-as-you-grow wavelength adds;
- Easy bit rate configuration for each wavelength;
- Simple facilitation of wavelength unbundling per operator, which supports governmental requirements for fiber sharing or co-investment partnership business models.

From an operational perspective, to upgrade a network from the legacy GPON to NG-PON2, existing GPON subscribers that will remain on GPON must be briefly out of service during installation of the coexisting element (CEx), after which the service is restored. After that, wavelength additions or changes will not impact existing subscribers except those being upgraded or migrated to new wavelengths.

TWDM PON's architecture enables the assignment of wavelengths to specific customers or applications. The wavelength design also enables a pay-as-you-grow platform. While GPON and asymmetric XG-PON (XG-PON1) can support mobile backhaul (MBH), TWDM PON can provide more bandwidth, thereby supporting more x-haul traffic. The assignment of wavelengths enables the support of enterprise services. In addition, TWDM PON was designed to allow point-to-point overlays for fronthaul support.

# Technologies beyond 10G PON

With the publication of XGS-PON and NG-PON2 standards by ITU-T, FSAN has delivered on their previous roadmap, and in November 2016, a new standards roadmap was released [9].

There were a set of key requirements to be met to enable the successful and cost-efficient deployment of future optical access network (F-OAN) technologies, namely in terms of spectral efficiency (SE), flexibility, extended reach, open access, and heterogeneous service convergence. [10].

At the end of 2019, ITU-T released the ITU-T G.9804.1 that defines the requirements for higher speed PON (HSP) [11]. The specifications of the PMD layer for 50G single-channel PON systems, ITU-T G.9804.3 recently approved [12], is already generating disagreement in the PON industry, where the downstream bandwidth is not gathering consensus, and now it seems probable that the world will be divided into two manufacturing and purchasing camps, the Western and the Chinese [13] [14].

The basic architectures of HSP systems can be split between TDM/TDMA-based, and P2P-based. In a higher speed multi-channel PON system, such as 50G TWDM PON, the OLT can be composed of multiple OLT channel terminations (CT) connected via a wavelength multiplexer (WM). In a 50G TDM PON, the OLT is a special case of a higher speed multi-channel PON system with just one channel in each direction [11].

A new PON-based 5G MFH (PON-MFH) was included as services categories supported in higher speed PON scenarios. The OLT and ONU provide transport between the control unit (CU) and the remote unit. Ultra-low latency with the use of cooperative dynamic bandwidth allocation (DBA) function and quiet window reduction for the PON is introduced. An interface named cooperative transport interface (CTI) between the 5G scheduler and a PON OLT/scheduler is defined by the O-RAN WG 4 group in collaboration with the ITU SG15 Q2 group [11].

50G TDM PON system, which operates over a single wavelength channel, shall be able to support a nominal line rate per fiber of approximately 50Gbit/s in the downstream direction and up to approximately 50Gbit/s in the upstream direction. A 50G TDM PON ONU shall be able to support the maximum service rate of approximately 40Gbit/s. An asymmetric nominal line rate combination options per wavelength channel should also be possible: 25Gbit/s in the upstream, 12.5Gbit/s, or 10Gbit/s in the upstream [11].

The 50G TWDM PON system is similar to the NG-PON2 system but at a higher speed per channel. To facilitate coexistence, an HSP system must be capable of reusing existing legacy ODN PON and ideally operate in a usable spectrum not occupied by legacy PON in a particular deployment. However, the new 50G-PON could reuse the spectrum allocated to legacy PON systems if it is not coexisting with those on the ODN. In certain approaches, and to facilitate the reuse of spectrum by using a common wavelength band, it could include multi-rate receivers. HSP systems must allow coexistence over the whole, end-to-end ODN, including coexistence over the feeder fiber by use of a CEx (or equivalent WDM). Besides, higher speed TDMA systems such as 50G TDM PON can use a multi-PON module integrated into the OLT PON port when coexisting with a legacy PON system [11].

HSP systems must allow a technology migration on existing infrastructure without any prolonged service interruption. It must be capable of upgrading single customers on demand. In any migration case including coexistence, the legacy ONU and OLT must remain unchanged and should not require any additional wavelength filters to protect them against HSP signals. If extra filtering is required, this should preferably be at the OLT, where access may be easier, and not in the ONU to avoid truck rolls to many locations of the ONU's [11].

A division is emerging between those in the 25G camp and opponents favoring 50G [13]. As so, several major communication industry operators and vendors announced, in October 2020, the signing of a 25G symmetric PON multi-source agreement (25GS-PON MSA) to promote and accelerate the development of 25GS-PON. The MSA Group has defined the 25GS-PON specification needed to address the gap between 10G XGS-PON and 50G PON in the ITU-T. The MSA was created after the ITU-T SG15/Q2 group did not reach a consensus to standardize 25GS-PON, which is seen as a crucial technology by many of the world's top operators and vendors [14].

The 25GS-PON MSA Group created a specification for 25GS-PON, which includes optical specifications based on the IEEE 802.3ca 25G/50G EPON standard, along with a transmission convergence (TC) layer that is an extension of XGS-PON [14]. A 25G TDM PON ONU shall be able to support the maximum service rate of approximately 25Gbit/s downstream and a symmetric nominal line rate of 25Gbit/s upstream. It will also be possible the support an asymmetric 10Gbit/s upstream.

As stated before, coexistence scenarios are becoming more and more difficult, and spectral scarcity is now a reality with multiple generations of PON technologies already on the field. With the technology spreading and multiple candidates, an investment decision for the next generation is becoming difficult. **Figure 4** presents and compares the wavelength candidates for HSP and 25G-PON with current PON technologies.

The 25G-PON can benefit from the optical technology already employed in data centers that leverage the best cost solution, high capacity, fastest time-to-market, and simplest evolution path compared to the 50G-PON that will require a massive technology jump or long time to mature.

With a minority coalition led by operators and vendors from China that objected to the proposal on the ground that 25G PON would pre-empt their futuristic vision of 50G PON (announcing the support of a global standard for PON technology that operates as high as 50Gbit/s and can be used for fixed broadband, optical LAN, cellular backhaul/fronthaul, and even optical access use), and a group in favor of initiating the 25G-PON standardization project [15] [16], the question arises: what will be the next PON technology?

We are impatient to see the standards "battle" resolved, whether that means China manufacturers work closely with existing standard bodies or whether other players worldwide get on board with "Fixed 5G" (F5G), so that the communications industry will benefit from volume shipments, and consumers may benefit with lower prices and new technology getting deployed sooner [15][16].

## New optical technologies for PON

Current PON optical technologies are based on bulk technology, like bi-directional optical sub-assembly (BOSA). It is also very common to have combined interfaces that allow multiple technologies to be handled within the same device, the so-called multi-pon module solutions. Current low-cost laser and receiver technologies face some challenges in delivering higher data

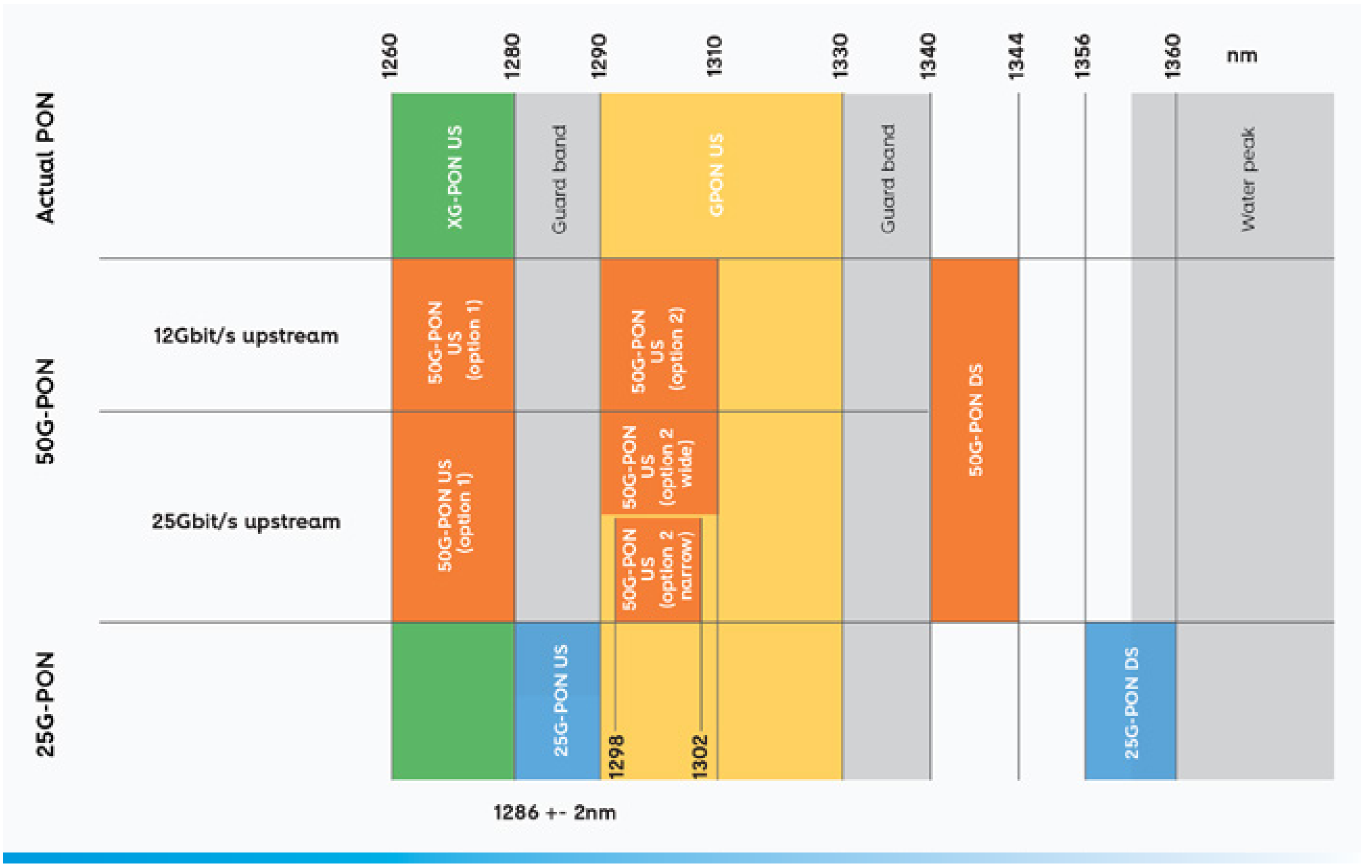


**FIGURE 4** – Coexistence possibilities, legacy PON, HSP-PON, and 25G-PON

rates without increasing packaging or electronic costs for future 50G-PON or 25G-PON.

Among PON future technologies, high interest has been given to the research/development of long reach/high-speed transmission, where optical amplifiers, electrical domain digital signal processing (DSP) to enhance the link budget, and/or transceiver technology are predicted to be key factors [17].

Similar to integrated circuits' contribution to electronics development, photonic integrated circuit (PIC) technology is one of the most attractive solutions to tackle the referred issues. Integrated photonics can have a key role in deploying more flexible PON networks, as they can incorporate different optical components with various functions in a potentially cost-effective way, without increasing the assembly process complexity [18] [19].

Photonic integration can provide advantageous solutions to PON by limiting the number of optical and electrical interconnections and thus overcoming some of the bulk packaging restrictions, such as bandwidth, power dissipation, and cost [20] [21]. Nevertheless, complexities can arise with the use of this technology, namely fiber interfacing difficulties, number of electrical connections, and possible high-density of components per device, which demands a high power dissipation management [22]. The development of PIC solutions for access networks has already been reported, e.g., with an indium phosphide-based (InP) monolithic transceiver PIC for NG-PON2 applications [23]. The proposed layout has the potential to be implemented as an OLT and with filter redesigning as an ONU. A photonic integrated apparatus for tunable multi-wavelength transmission was patented in 2017 [24]. The TWDM-PON transmitter system proposed is tailored to support current and next-generation access technologies.

As addressed in previous sections, the major requirement for future PON technologies is the need for coexistence with current deployed PON systems [20] [22]. The longer the required reach, the more difficult it gets to find the laser technology capable of supporting the demanded distance. To improve reach, several techniques are available, and many stem from the laser (e.g., low dynamic chirp or frequency modulation efficiency), laser driving (pre-chirping or equalization), and wavelength selection (e.g., O-band instead of C- and L-bands) [22] [25]. O-band has been used to support upstream, and was adopted by some of the standards like GPON, XGS-PON, and now 25G-PON and HSP. Besides presenting low or null dispersion, O-band only introduces slightly higher attenuation than C-band. To cope with the maturity of the technology and promote an easier and simplified entry into the market, initial PON technologies, like GPON, were set in large bandwidths for better yield in laser choice with the upstream in the O band [18] [26]. The wavelength range of 20nm to 30nm per traffic direction was reserved for this technology, which allowed it to easily mature while still being competitive. This strategy proved to be solid since it resulted in the current GPON BOSA sitting in the few dollars range (as of today).

Furthermore, PON technology evolution can be achieved by data rate multiplication and more efficient use of the bands to promote further network evolution scenarios. Following this path, the XGS-PON standard was conceived with slightly smaller bandwidths for upstream and downstream, resulting in a four-times higher bitrate than GPON [3] [8]. Newer PON technologies, as NG-PON2, require finer tuning, hence, a more complex laser selection process. The qualification of a laser to operate in a certain wavelength range results from setting its maximum allowed wavelength at initial temperatures. The broad requirements of the technology, in terms of the client locations, may require industrial temperature ranges (−40°C to 85°C), which bring extra requisites to the laser wavelength choice or thermal control mechanisms. Directly modulated lasers have good optical output power and are easy to drive and modulate. However, the inherent high wavelength fluctuation when modulated or the inherent chirp can result in propagation limitations. Laser design/control efforts are being made to minimize these effects, and currently, there are already some devices in the market able to cope with some of the most stringent standard requirements [27], e.g., the NG-PON2. With an external cavity, externally-modulated lasers (EML) result in a much lower chirp, however, typically having a more complex tunability mechanism when compared to the simple current or thermal tuning of directly modulated lasers (DML) [18].

Photonic packaging technology has achieved a higher significance under optical communication systems' recent developments [28] by covering the optical and electronic connections in/out of the PIC. Packaging process developments are of great importance for the next generation of optical components [29]. Being one of the most complex segments of the integrated component viability, it can pose several challenges, such as limitation s concerning volume, cost, RF performance, power dissipation, and its high-volume manufacturing capability [28], which can highly impact the cost of the solution. Currently, the packaging is seen as one of the most significant bottlenecks in the development of commercially relevant PIC devices [30] [31]. The packaging design flow is divided into three main areas: the optical design, the electrical design, and the thermal management of the module.

The different PON standards and technologies have their requirements in terms of complexity control, especially for tunable devices. When wavelength control is not essential, simpler actuation systems with lower power are required. Nonetheless, the options have to be restricted once the wavelength spectrum becomes more crowded and the requirements for more complex control increase [18]. **Figure 5** summarizes the technology and expected power for its optoelectronic interfaces versus the complexity and requirements for a certain interface. A general sweep, from low data rate with large wavelength range to higher data rate with tighter wavelength range and longer reaches, is also presented. Additionally, the technologies with an approximate relative power requirement classification (from low to high power) are also

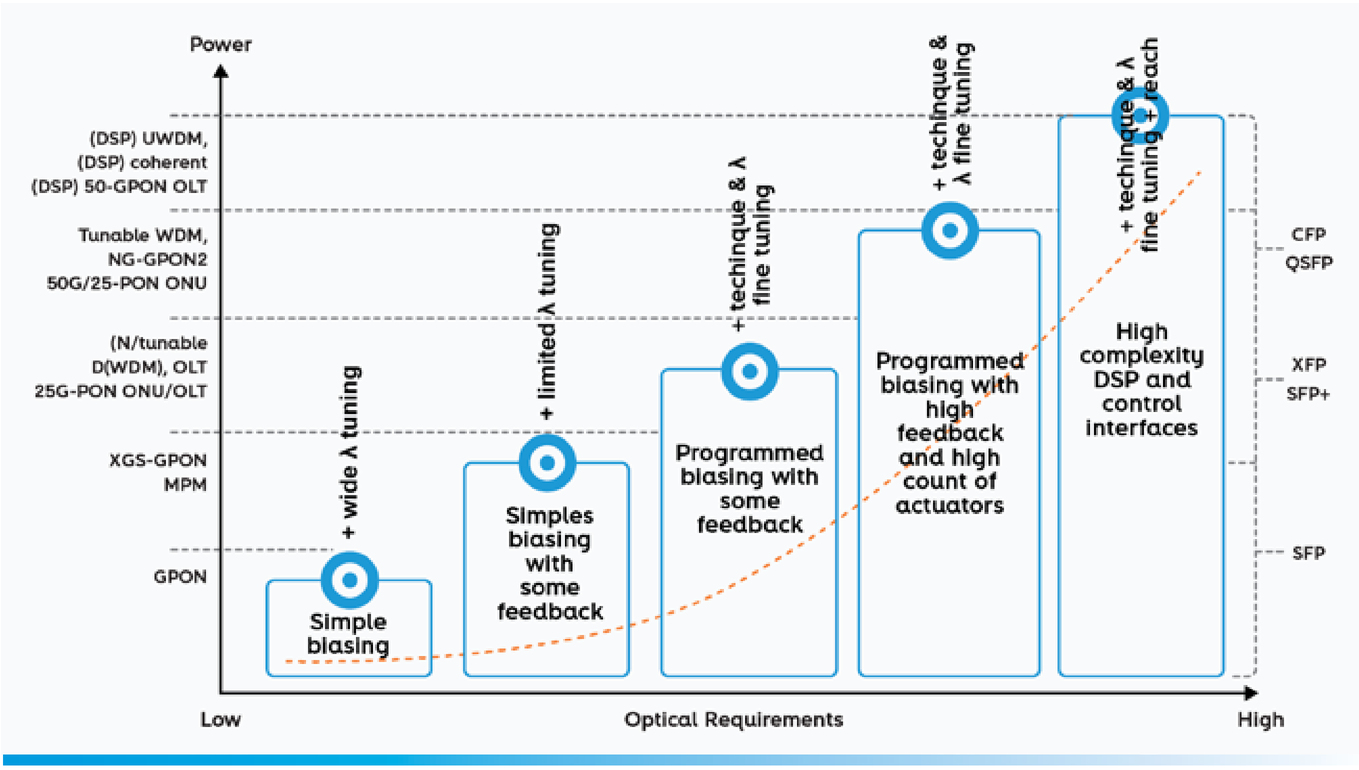


**FIGURE 5** – Diagram of requirements in terms of control, complexity, and power for different technologies

identified. The x-axis represents the optical requirements, ranging from low data rate to long-reach dense wavelength division multiplexing (DWDM) and high data rate. The circles describe the complex steps from the system requirements.

Potential form factor solutions, able to cope with the required power dissipation, are also presented in the far right of **Figure 5**. Technology evolution poses increasing challenges in the control complexity and required power. As the demanded power grows, a change in the form factor is needed. Form factors have two major characteristics: minimum volume and maximum dissipated power [32].

For the 50G-PON and 25G-PON, high complexity is expected on both sides, mainly on the 50Gbit/s processing, where DSP will play a major role in meeting the high loss ODN requirements of PON. Also, tight control of the lasers working on the O-band for both directions will require complex techniques and careful laser selections, due to the low spectral scarcity.

An interesting point on the 25G-PON is that currently available technology for 25G Ethernet and 100G Ethernet (4*25Gbit/s) will speed up its deployment due to the high market availability for data centers. Unlike the 50Gbit/s downstream of HSP, requiring a more complex structure downstream, both at the transmission of OLT and reception of ONU, the use of non-return-to-zero (NRZ) signals poses high RF bandwidth of lasers and avalanche photodiodes (APD), and lasing technology (nowadays on a limited laboratory availability) of single wavelength 100G, 400G, and 800G Ethernet. Therefore, high-speed Ethernet technology, namely 400GbE, 800GbE is moving from NRZ to pulse amplitude modulation 4-level (PAM4), posing more challenges for the 50G-PON. An alternative is to use 25G optics with strong DSP capabilities.

The most cost sensitivity part of an HSP ONU is the optics for the 50Gbit/s. As stated before, in the HSP system, 10Gbit/s and 25Gbit/s upstream look to be possible using conventional optics without wavelength control, unlike the 50Gbit/s upstream where the link budget is very overextended.

There are several methods to solve the 50Gbit/s upstream and downstream power budget requirement and also enable coexistence with legacy systems and lower upstream line rate.

For 10G and 25G upstream, the temperature control will bring a high added cost for the ONU transmitter. The 50Gbit/s upstream must be cooled to meet the required power budget.

Nowadays, a 50Gbit/s DML is not mature. Due to the very small size of the 50Gbit/s DML chip, the uncooled 50Gbit/s DML can only transmit very low launch power with very low extinction ratio (ER), and is not likely to meet the power budget requirement for HSP PON upstream [32] . A more practical solution is to use a high launch power 50Gbit/s EML or a 50Gbit/s EML with an integrated semiconductor optical amplifier. Regarding the receiver of the HSP ONU for 50Gbit/s, there exist two possible solutions: 1) 25Gbit/s APD, a trans-impedance amplifier (TIA), and a DSP; and 2) a pre-amplifier receiver that is composed by an semiconductor optical amplifier, a band-pass filter, 25Gbit/s APD, a TIA, and DSP. The cost of a pre-amplifier receiver is at least 20% more than the simple solution [32]. With the previous assumptions, a long technical way to reach a cost-effective solution for ONU is expected to reach the requirements for the HSP for 50Gbit/s.

PIC are a promising technology with great potential in several fields, including telecom, sensing, and bio-photonics. Depending on the requirements, the type of materials, and components, a tailored approach has to be carefully specified for the different PON technology standards. The different materials used in the available solutions for PIC implementation result in different behaviors, steps, processes, and capabilities. The main constraint of PIC is still the limited gain band of the active devices in its core. This may imply advanced processing and/or packaging techniques to be able to cope with the existing standards, e.g., regrowth and hybrid packaging. After carefully choosing the standard to be followed and the packaging approach, its control complexity must also be cautiously considered to guarantee that the solution is feasible and adapted. Specifically for PON, the most stringent requirements are the cost and robustness of the proposed solution. Several challenges must be considered when equating the introduction of PIC in the next-generation PON, like productization, wideband wavelength range (O-, C-, and L bands), laser control, and tunability mechanisms [18].

PON standards have different flavors that result in quite different requirements, especially regarding the wavelength ranges to be covered by the two traffic directions, i.e., the upstream and downstream. For instance, GPON and XGS-PON have >200nm spacing between upstream and downstream specifications, while NG-PON2 requires around 60nm for the same parameter. Due to the inherent limitations of some technologies, hybrid integration may be required, e.g., XGS-PON and GPON. Smaller bands will ease this process and therefore potentiate monolithic PIC implementation, simplifying packaging and deployment, e.g., NG-PON2 [18].

PIC have typically two major interfaces, electrical and optical, each with different requirements, techniques, and available materials to be used. Packaging and technical considerations, such as size, power, RF compliance, and sealing, are relevant. In a nutshell, manufacturability is anticipated to be one of the most critical steps for the technology to succeed, especially in PON. In our vision, the use of PIC in PON and other subsystems is very close to being an effective reality with prospective advantages [18].

# Conclusions

The metamorphosis of PON technologies to support everything from residential services, Wi-Fi, high resiliency services, high bit-rate services, to RAN applications is notorious. It makes PON equipment, namely OLT and ONU, the most adaptable telecom equipment to the preferred scenario and the most diffused technology.

The access network of the future has to be prepared, including serving several segments and different backhaul features. It will be a truly multi-service solution. The Communication on Connectivity for a European Gigabit Society (Sept 2016) sets a vision of Europe where availability and take-up of very high-capacity networks enable the widespread use of products, services, and applications in the Digital Single Market. This vision relies on the three main strategic objectives for 2025: gigabit connectivity, 5G coverage for all urban areas and all major terrestrial transport paths, and access for all European households to connectivity offering at least 100Mbit/s.

The actual economic scene benefits ecologic and low power consumption solutions due to resource exhaustion, global warming, and protecting the planet. Expectations about the increasing levels of energy consumption associated with the growing demands for broadband services are raising concerns and calls for the implementation of energy-efficient equipment and strategies. The latter is gaining growing attention, driven both by ecologic and economic values.

The need to achieve significant breakthroughs in network energy efficiency requires the integration of hardware enhancements with adequate energy-saving mechanisms that explicitly manage network delivery performance and resource consumption. Power saving in telecommunication network systems has become an increasingly important concern due to three factors: reducing operators' OPEX, reducing the network contribution to greenhouse emission gases, and legislation. Next-generation equipment should be as efficient as possible for allowing minimal energy cost per bit. Equipment is the one that effectively consumes the power in passive ODN.

The 2008 Code of Conduct by the European Commission Joint Research Centre [33] sets out the basic principles to be followed by all parties involved in broadband equipment operating in the European Community regarding energy-efficient equipment. In the United States, the Energy Star program identifies and promotes energy efficiency for small network equipment.

# References

**[1]** ITU-T, G.987 *Series of Recommendations, "10-Gigabit-capable passive optical network (XG-PON) systems"*, 2012

**[2]** ITU-T, *Recommendation G.988: ONU management and control interface (OMCI) specification*, 2017

**[3]** ITU-T, *Recommendation G.9807.1: 10-Gigabit-capable symmetric passive optical network (XGS-PON)*, 2016

**[4]** ITU-T, *Recommendation G.984.5 : Gigabit-capable passive optical networks (G-PON): Enhancement band - Amendment 2*, 2020

**[5]** M. Carroll, D. Nesset and P. Dawes, *FSAN Highlights & NG-PON2 Standards Update, FSAN IEEE NG-EPON/1904 ANWG Joint Session*, 2015

**[6]** ITU-T, *Recommendation G.989.3: 40-Gigabit-capable passive optical networks (NG-PON2): Transmission convergence layer specification*, 2021

**[7]** ITU-T, *Recommendation G.989.1: 40-Gigabit-capable passive optical networks (NG-PON2): General requirements*, 2013

**[8]** ITU-T, *Recommendation G.989.2: 40-Gigabit-capable passive optical networks 2 (NG-PON2): Physical media dependent (PMD) layer specification*, 2019

**[9]** FSAN, "FSAN Standard," [Online]. Available: https://www.fsan.org/roadmap/

**[10]** A. Shahpari, R. M. Ferreira, F. P. Guiomar, S. B. Amado, S. Ziaie, C. Rodrigues, J. D. Reis, A. N. Pinto and A. L. Teixeira, "Real-Time Bidirectional Coherent Nyquist UDWDM-PON Coexisting With Multiple Deployed Systems in Field-Trial," *Journal of Lightwave Technology*, vol. 34, no. 7, pp. 1643-1650, 2016

**[11]** ITU-T, *Recommendation G.9804.1: Higher speed passive optical networks - Requirements*, 2019

**[12]** ITU-T, *Recommendation G.9804.3 : 50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification*, 2021

**[13]** M. Warwick, "Finnish phoenix introduces the world's first commercial 25 Gbps symmetrical PON," 2020. [Online]. Available: https://www.telecomtv.com/content/access-evolution/finnish-phoenix-introduces-the-worlds-first-commercial-25-gbps-symmetrical-pon-40266/

**[14]** 25GS-PON MSA Group, "25GS-PON MSA Group," 2021. [Online]. Available: https://www.25gspon-msa.org/

**[15]** C. Depuy and A. Weckel, "HUAWEI PROVIDES 2020 MEETING UPDATE," 650 Group Market Intelligence Research, 2020. [Online]. Available: https://www.650group.com/blog/huawei-has2020-meeting-update

**[16]** C. Depuy and A. Weckel, "OFC 2018 THEME: 400 GBPS," 650 Group Market Intelligence Research, 2018. [Online]. Available: https://www.650group.com/blog/ofc-2018-theme-400-gbps

**[17]** V. O'Byrne, C. H. Lee, Y. Kim and Z. Zhao, "Optical Fiber Telecommunications VIB: Chapter 24. FTTX Worldwide Deployment," Elsevier Inc. Chapters, 2013

**[18]** C. Pinho, F. Rodrigues, A. M. Tavares, C. Rodrigues, C. E. Rodrigues and A. Teixeira, "Photonic Integrated Circuits for NGPON2 ONU Transceivers (Invited)," Applied Sciences, vol. 10, no. 11, p. 4024, 2020

**[19]** A. Teixeira, "NG-PON2 direct modulation-based optics status and evolution path," in *Broadband Forum Broadband Acceleration Seminar: NG-PON2 Roadmap and Evolution—A Universal Platform for Residential, Business, and Wireless/5G? In Proceedings of the OFC 2019—Optical Fiber Communications Conference*, San Diego, CA, USA, 2019

**[20]** F. Effenberger, "PONs: State of the Art and Standardized," in *Optical Fiber Telecommunications VIB: Systems and Networks: Sixth Edition*, 2013, pp. 891-925

**[21]** I. A. Alimi, A. Tavares, C. Pinho, A. M. Abdalla, P. P. Monteiro and A. L. Teixeira, "Enabling Optical Wired and Wireless Technologies for 5G and Beyond Networks," 2019

**[22]** C. F. Lam and S. Yin, "Evolution of fiber access networks," in *Optical Fiber Telecommunications VII*, Elsevier, 2020, pp. 827-865

**[23]** A. Tavares, A. Lopes, C. Rodrigues, P. Mãocheia, T. Mendes, S. Brandão, F. Rodrigues, R. Ferreira and A. Teixeira, "Photonic integrated transmitter and receiver for NG-PON2," in *Second International Conference on Applications of Optics and Photonics}*, International Society for Optics and Photonics, 2014, p. 928605

**[24]** A. L. J. TEIXEIRA, A. C. M. TAVARES, A. P. S. LOPES and C. E. RODRIGUES, "Photonic integrated tunable multi-wavelength transmitter circuit". Patent US Patent 10,326,529, 18 June 2019

**[25]** A. Shahpari, R. M. Ferreira, R. S. Luis, Z. Vujicic, F. P. Guiomar, J. D. Reis and A. L. Teixeira, "Coherent Access: A Review," *Journal of Lightwave Technology*, vol. 35, no. 4, pp. 1050-1058, 2017

**[26]** E. Wong, "Next-Generation Broadband Access Networks and Technologies," *Journal of Lightwave Technology*, vol. 30, no. 4, pp. 597-608, 2012

**[27]** PICadvanced, "XFP NG-PON2 ONU Class 3," PICadvanced, 2019. [Online]. Available: https://www.picadvanced.store/product-page/xfp-ng-pon2-onu-class-3

**[28]** N. Pavarelli, J. S. Lee and P. A. O'Brien, "Packaging challenges for integrated silicon photonic circuits," *Silicon Photonics and Photonic Integrated Circuits IV*, vol. 9133, pp. 48-56, 2014

**[29]** S. Latkowski, D. Pustakhod, M. Chatzimichailidis, W. Yao and X. J. M. Leijtens, "Open Standards for Automation of Testing of Photonic Integrated Circuits," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 25, no. 5, pp. 1-8, 2019

**[30]** M. Liehr, M. Baier, G. Hoefler, N. M. Fahrenkopf, J. Bowers, R. Gladhill, P. O'Brien, E. Timurdogan, Z. Su and F. Kish, "Foundry capabilities for photonic integrated circuits," in *Optical Fiber Telecommunications VII*, Elsevier, 2020, pp. 143-193

**[31]** L. Carroll, J.-S. Lee, C. Scarcella, K. Gradkowski, M. Duperron, H. Lu, Y. Zhao, C. Eason, P. Morrissey, M. Rensing, S. Collins, H. Y. Hwang and P. O'Brien, "Photonic Packaging: Transforming Silicon Photonic Integrated Circuits into Photonic Devices," *Applied Sciences*, vol. 6, no. 12, 2016

**[32]** B. Mack and T. Graham, "Pluggable Optics Modules – Thermal Specifications, Part 1," Electronics Cooling, 2016. [Online]. Available: https://www.electronics-cooling.com/2016/07/pluggable-optics-modules-thermal-specifications-part-1/

**[33]** European Commission Joint Research Centre, "Code of Conduct on Data Centres Energy Efficiency," 2008

# Acronyms & Terms

**2**

**25G/50G EPON** IEEE 802.3ca Standard
**25GS-PON** 25G Symmetric PON
**2FA** Two-Factor Authentication

**3**

**3D** Three-dimensional
**3GPP** Third Generation Partnership Project, a collaboration between groups of telecommunications standards associations

**4**

**4G** Fourth generation mobile networks

**5**

**5G** Fifth generation mobile networks
**5G-AKA** 5G Authentication and Key Agreement
**5GC** 5G Core
**5G-RG** 5G Residential Gateways

**A**

**ABC** Altice Labs' Advanced Business Communication
**ACM** Altice Labs' Active Campaign Manager
**AF** Application Function
**AGF** Access Gateway Function
**AGV** Automated Guided Vehicle
**AI** Artificial Intelligence
**AMF** Access and Mobility Management Function
**APA** Administração do Porto de Aveiro, S.A.
**APD** Avalanche Photodiode
**API** Application Programming Interface
**APP** Application
**AR** Augmented Reality
**ATSSS** Access Traffic Steering, Switching and Splitting

**B**

**B2B** Business-to-Business
**B2C** Business-to-Consumer
**BBF** Broadband Forum
**BM** Burst Mode
**BNG** Broadband Network Gateway
**BOSA** Bi-directional Optical Sub-Assembly
**Bot** A software application that runs automated tasks over the Internet

**C**

**CAGR** Compound Annual Growth Rate
**CAPEX** Capital Expenditures
**CCaaS** Contact Center as a Service
**CDR** Clock and Data Recover
**CDR** Call Detail Records
**CEO** Chief Executive Officer
**CEx/CEMx** Coexistence Element
**CFP** 100 Gigabit SFP
**CI/CD** Continuous Integration/ Continuous Delivery
**CNI** Container Network Interface
**COTS** Commercial Off-The-Shelf
**COVID** Coronavirus disease 2019
**CP** Control Plane
**CPaaS** Communications Platform as a Service
**CPU** Central Processing Unit
**CRM** Customer Relationship Management
**CSP** Communications Service Providers

| | | |
|---|---|---|
| | **CT** | Channel Terminations |
| | **CTI** | Cooperative Transport Interface |
| | **CU** | Centralized Unit |
| | **CUPS** | Control and User Plane Separation |

| | | |
|---|---|---|
| **D** | **DBA** | Dynamic Bandwidth Allocation |
| | **DevOps** | Software development methodology that combines software development with information technology operations |
| | **DMA** | Direct Memory Access |
| | **DML** | Directly Modulated Laser |
| | **DN** | Data Network |
| | **DOCSIS** | Data Over Cable System Interface Specification, an international telecommunications standard |
| | **DP** | Data Plane |
| | **DPA** | Data Plane Abstraction |
| | **DPDK** | Data Plane Development Kit |
| | **DS** | Downstream |
| | **DSP** | Digital Signal Processing |
| | **DTMF** | Dual Tone Modulated Frequency |
| | **DU** | Distributed Unit |
| | **DWBA** | Dynamic Wavelength and Bandwidth Allocation |
| | **DWDM** | Dense Wavelength Division Multiplexing |

| | | |
|---|---|---|
| **E** | **EAP** | Extensible Authentication Protocol |
| | **EAP-AKA'** | EAP Authentication and Key Agreement Prime |
| | **EAP-TLS** | EAP Transport Layer Security |
| | **EAP-TTLS** | EAP Tunneled Transport Layer Security |
| | **eBPF** | extended Berkeley Packet Filter |
| | **eMBB** | enhanced Mobile BroadBand |
| | **EML** | Externally-Modulated |
| | **EPC** | Evolved Packet Core |
| | **ER** | Extinction Ratio |
| | **ESB** | Enterprise Service Bus |
| | **ETSI** | European Telecommunications Standards Institute |
| | **EU** | European Union |

| | | |
|---|---|---|
| **F** | **F5G** | Fixed 5G |
| | **FAQ** | Frequently Asked Questions |
| | **FH** | Front Haul |
| | **FMC** | Fixed Mobile Convergence |
| | **FN-RG** | Fixed-Network Residential Gateways |
| | **F-OAN** | Future Optical Access Network |
| | **FPGA** | Field Programmable Gate Array |
| | **FSAN** | Full Service Access Network |

| | | |
|---|---|---|
| **G** | **GDPR** | General Data Protection Regulation |
| | **GF** | Gateway Function |
| | **gNB** | Next Generation NodeB |
| | **GPON** | Gigabit Passive Optical Network |
| | **GW** | Gateway |

| | | |
|---|---|---|
| **H** | **High Phy** | Higher part of the Physical layer of the OSI reference model |
| | **HSP** | Higher Speed PON |
| | **HW** | Hardware |

| | | |
|---|---|---|
| **I** | **I/O** | Input/Output |
| | **ICT** | Information and Communications Technology |
| | **ID** | Identifcation/Identifer |

| | |
|---|---|
| **IETF** | Internet Engineering Task Force, an open standards organization that develops and promotes voluntary Internet standards |
| **IMSI** | International Mobile Subscriber Identity |
| **INESC TEC** | Instituto de Engenharia de Sistemas e Computadores, Tecnologia e Ciência |
| **InP** | Indium Phosphide |
| **IOMMU** | Input-Output Memory Management Unit |
| **IoT** | Internet of Things |
| **IP** | Internet Protocol |
| **IPC** | Inter-Process Communication |
| **IPTV** | Internet Protocol Television |
| **IRQ** | Interrupt Request |
| **IT** | Information Technologies |
| **IT-Aveiro** | Instituto de Telecomunicações, Aveiro |
| **ITU** | International Telecommunication Union |
| **ITU-T** | International Telecommunication Union, Telecommunication Standardization Sector |
| **ITU-T SG15 Q2** | ITU-T's transport, access and home study group, optical systems for fibre access networks question |
| **IVR** | Interactive Voice Response |
| **IWF** | Interworking Function |

## L

| | |
|---|---|
| **LA** | Limiting Amplifier |
| **LAN** | Local Area Network |
| **LD** | Laser Diode |
| **LED** | Light Emitting Diode |
| **LKM** | Linux Kernel Modules |
| **Low Phy** | Lower part of the Physical layer of the OSI reference model |
| **LTE** | Long Term Evolution |

## M

| | |
|---|---|
| **MBH** | Mobile BackHaul |
| **MEC** | Multi-access Edge Computing |
| **MEO** | Mobile and fixed telecommunications service and brand from Altice Portugal |
| **MH** | Middle Haul |
| **MIMO** | Multiple-Input/Multiple-Output |
| **ML** | Machine Learning |
| **mMTC** | massive Machine Type Communications |
| **MNO** | Mobile Network Operator |
| **MOCN** | Multi-Operator Core Network |
| **MP-DCCP** | Multipath-Datagram Congestion Control Protocol |
| **MPLS** | Multiprotocol Label Switching |
| **MPM** | Multi-PON Module |
| **MP-QUIC** | Multipath Quick UDP Internet Connections |
| **MP-TCP** | Multipath Transmission Control Protocol |
| **MR-DC** | Multi-Radio Dual Connectivity |
| **MSA** | Multi-Source Agreement |
| **µs** | Micro-Service |

## N

| | |
|---|---|
| **N3IWF** | Non-3GPP Interworking Function |
| **NAPI** | New API |
| **NAS** | Non-Access Stratum |
| **NAT** | Network Address Translation |
| **NB-IoT** | Narrow Band IoT |
| **NEF** | Network Exposure Function |
| **NF** | Network Function |
| **NFV** | Network Function Virtualization |
| **ng-eNB** | Next-Generation e-NodeB |
| **NG-PON** | Next Generation PON |
| **NG-PON2** | Next Generation PON 2, a 40 Gbit/s capable multi-wavelength PON system |
| **NIC** | Network Interface Card |
| **NLP** | Natural Language Processing |
| **NPN** | Non-Public Networks |
| **NR** | New Radio |
| **NRF** | Network Function Repository Function |

| | |
|---|---|
| **NRZ** | Non-Return-to-Zero |
| **NSA** | Non-Standalone |

**O**

| | |
|---|---|
| **OCP** | Open Compute Project, an organization that shares designs of data centre products among companies |
| **O-CU** | Open CU |
| **ODN** | Optical Distribution Network |
| **O-DU** | Open DU |
| **OLT** | Optical Line Termination |
| **OMCI** | ONU Management and Control Interface |
| **ONF** | Open Networking Foundation, a user-driven organization dedicated to the promotion and adoption of SDN through open standards development |
| **ONT** | Optical Network Terminal |
| **ONU** | Optical Network Unit |
| **OpenNESS** | Intel Open Network Edge Services Software |
| **OpenRAN** | Industry-wide interface standards based on interoperability and standardization of RAN elements |
| **OPEX** | Operational Expenditures |
| **O-RAN ALLIANCE** | Global community of more than 300 companies operating in the RAN industry |
| **O-RAN WG4** | O-RAN ALLIANCE Open Fronthaul Interfaces Workgroup |
| **O-RU** | Open RU |
| **OS** | Operating System |
| **OTT** | Over-the-Top |
| **OVS** | Open vSwitch, an open source implementation of a distributed virtual multilayer switch |

**P**

| | |
|---|---|
| **P2P** | Point-to-Point |
| **PAM4** | Pulse Amplitude Modulation 4-level |
| **PCF** | Policy Control Function |
| **PCI** | Peripheral Component Interconnect |
| **PCIe** | PCI express |
| **PCI-SIG** | Peripheral Component Interconnect Special Interest Group, an electronics industry consortium |
| **PDU** | Protocol Data Unit |
| **PF** | Physical Function |
| **PIC** | Photonic Integrated Circuit |
| **PLMN** | Public Land Mobile Network |
| **PMD** | Physical Media Dependent |
| **PNI-NPN** | Public Network-Integrated NPN |
| **PoE** | Power-over-Ethernet |
| **PON** | Passive Optical Network |
| **PSA** | PDU Session Anchor |

**Q**

| | |
|---|---|
| **QoS** | Quality of Service |
| **QOSA** | Quad Optical Sub-Assembly |
| **QSFP** | Quad SFP |

**R**

| | |
|---|---|
| **RAN** | Radio Access Network |
| **RDI** | Research, Development and Innovation |
| **RF** | Radio Frequency |
| **RGB** | Red-Green-Blue |
| **RPA** | Robot Process Automation |
| **RU** | Radio Unit |
| **RX** | Reception |

**S**

| | |
|---|---|
| **SaaS** | Software as a Service |
| **SBA** | Service-Based Architecture |
| **SCP** | Service Communication Proxy |
| **SDG** | Sustainable Development Goals |
| **SDN** | Software-Defined Network |

| | |
|---|---|
| **SDO** | Standards Development Organization |
| **SE** | Spectral Efficiency |
| **SFP** | Small Form-factor Pluggable |
| **SFP+** | 10Gbps SFP |
| **SHAP** | SHapley Additive exPlanations |
| **SIP** | Session Initiation Protocol |
| **SLA** | Service Level Agreement |
| **SMB** | Small and Medium Businesses |
| **SMF** | Session Management Function |
| **SMS** | Short Message Service |
| **SNA** | Social Network Analysis |
| **SNPN** | Standalone NPN |
| **SoA** | Service-Oriented Architecture |
| **SR-IOV** | Single Root I/O Virtualization |
| **SRP** | Single-Responsibility Principle |
| **SW** | Software |
| **SW** | Switch |

**T**

| | |
|---|---|
| **TBI** | Traumatic Brain Injury |
| **TC** | Transmission Convergence |
| **TCO** | Total Cost of Ownership |
| **TDD** | Time Division Duplex |
| **TDM** | Time Division Multiplexing |
| **TDMA** | Time-Division Multiple Access |
| **TELCO/ TELCOS** | Telecommunication Operators |
| **TH** | Threshold |
| **TIA** | Trans-Impedance Amplifier |
| **TIP** | Telecom Infra Project |
| **TLS** | Transport Layer Security |
| **TNGF** | Trusted Non-3GPP Gateway Function |
| **TSN** | Time-Sensitive Network |
| **TSVWG** | IETF's Transport Area Working Group |
| **TV** | Television |
| **TWDM** | Time Wavelength Division Multiplexing |
| **TWIF** | Trusted WLAN Interworking Function |
| **TX** | Transmission |

**U**

| | |
|---|---|
| **UA** | University of Aveiro |
| **UAb** | Universidade Aberta |
| **UCaaS** | Unified Communication as a Service |
| **UDP** | User Datagram Protocol |
| **UN** | United Nations |
| **UPF** | User Plane Function |
| **URLLC** | Ultra-Reliable Low-Latency Communication |
| **US** | Upstream |
| **USIM** | Universal Subscriber Identity Module |
| **UTAD** | University of Trás-os-Montes and Alto Douro |

**V**

| | |
|---|---|
| **V2X** | Vehicle-to-everything |
| **vBNG** | Virtual BNG |
| **VF** | Virtual Functions |
| **VM** | Virtual Machine |
| **VMM** | Virtual Machine Monitor |
| **vNIC** | Virtual NIC |
| **VoIP** | Voice over IP |
| **VPN** | Virtual Private Network |
| **VPP** | Vector Packet Processing |
| **VR** | Virtual Reality |

**W**

| | |
|---|---|
| **W-5GAN** | Wireline 5G Access Network |
| **W-AGF** | Wireline Access Gateway Function |
| **WBF** | Wireless Broadband Alliance |
| **WDM** | Wavelength Division Multiplexer |
| **WDM1r** | WDM 1 type r |
| **Wi-Fi** | IEEE 802.11x - Wireless Network (Wi-Fi Alliance) |
| **WLAN** | Wireless LAN |
| **WM** | Wavelength Multiplexer |
| **WMS** | Windless Media Server |
| **WWC** | Wireline-Wireless Convergence |

| | | |
|---|---|---|
| X | **XaaS** | Everything-as-a-Service |
| | **xAPI** | experience API |
| | **XDP** | eXpress Data Path |
| | **XFP** | 10 Gigabit SFP |
| | **XG-PON** | 10-Gigabit-capable PON, defined by ITU-T G.987 standard |
| | **XG-PON1** | 10-Gigabit-capable Asymmetric PON |
| | **XGS-PON** | 10-Gigabit-capable Symmetrical PON |
| | **xHaul** | Converged optical and wireless network solution able to flexibly connect small cells to the core network |
| | **xPON** | Designation for several PON technologies |
| | **XR** | eXtended Reality |
| | **xWDM** | The technology of wavelength-division multiplexing |

# Acknowledgments

Year after year, InnovAction is the result of powerful teamwork. Several persons from Altice Labs get involved and, along with external partners, contribute with their knowledge and time to grant this magazine's quality and ensure each edition has a diversified collection of articles.

Thus, we would like to thank all authors (identified in each article) for their contributions and share the knowledge resulting from their research and work.

We also want to leave a note of gratitude to all technical and editorial reviewers that did a meticulous job on improving all articles' quality and excellence and, therefore, of the entire magazine.

Finally, a special word and acknowledgment to our designer for the excellent job of granting an appealing and coherent design across the entire magazine.

**Strategic team:**
Ana Patrícia Monteiro, Fausto de Carvalho, Mário Rui Costa, Paula Cravo, Paulo Pereira and Pedro Carvalho

**Editorial team:**
Ana Patrícia Monteiro and Paula Cravo

**Art coordinator and graphic edition:**
Cátia Santos Pinto

**Technical reviewers team:**
Ana Patrícia Monteiro, Bruno Vitor Cabral, Clara Guerra, Fausto de Carvalho, Fernando Morgado, Jorge Carapinha, Lourenço Moura, Luís Cortesão, Mário Rui Costa, Paula Cravo, Rui Filipe Pedro and Suzete Simões

Aveiro, Portugal | December 2021

www.alticelabs.com