altice labs

InnovAction

#7 | December 2022

Technological evolution is the result of our own desire to lead a better life.

- R.S. Amblee

InnovAction

#7 | December 2022

Title
Innovaction
Altice Labs journal

Edition
2022

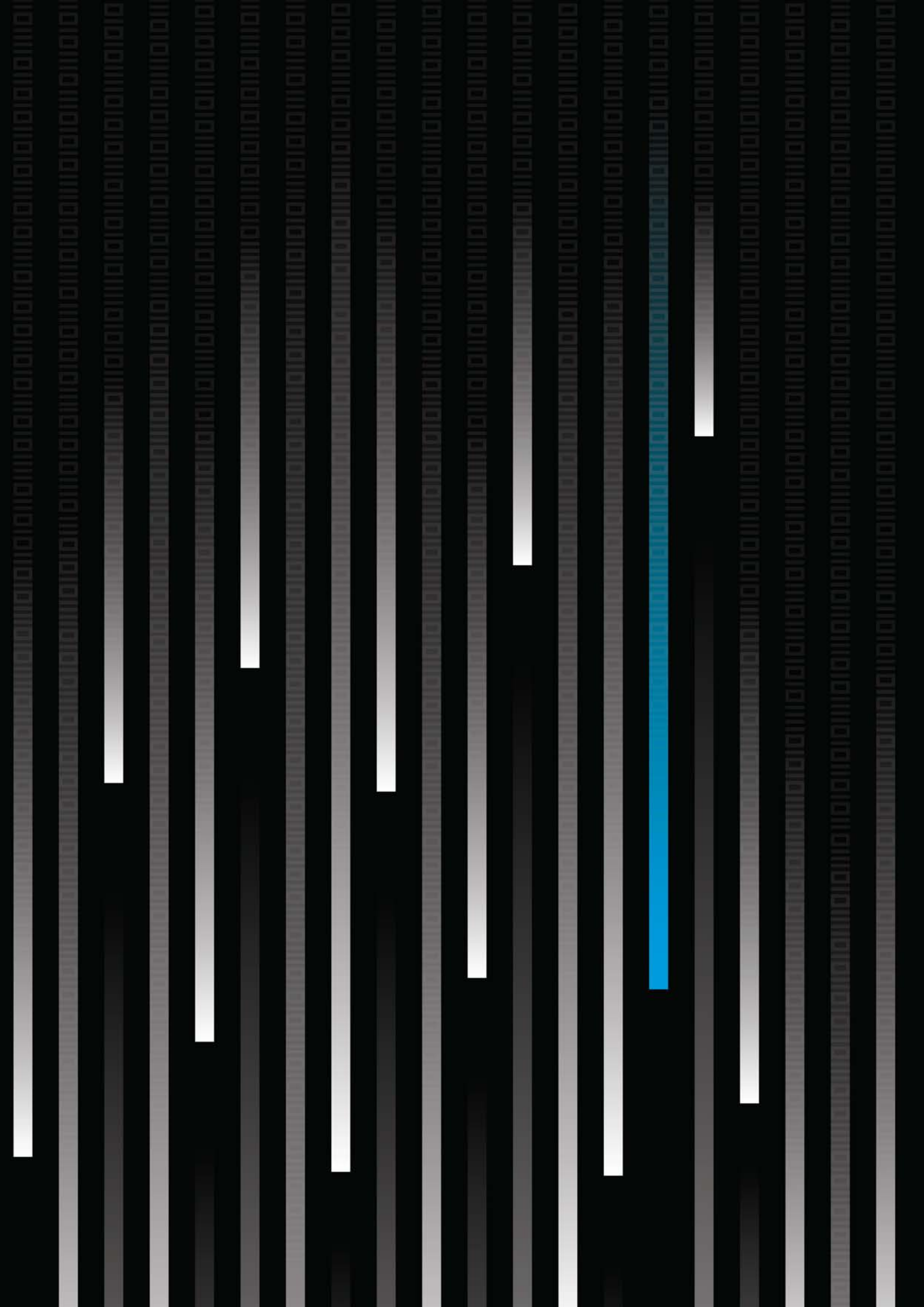
Design
Altice Labs

Printing and finishing
Lusoimpress - Artes Gráficas, S.A.
250 copies

Legal deposit
512167/23

ISSN | DOI
2975-8459 | 10.57650/innovaction

altice
labs




Net Worth and Forecast
Revenue
Total: 2.1337.101
Invoices
60% paid last year
30% paid last month
80% paid last month
Earnings

One step beyond!

As the years of isolation and full remote slowly fade out and new world challenges appear, Digital Service Providers - DSP - are grabbing the silver lining market opportunity created by the last unstable years to design and implement robust technology solutions beyond the "disappearing" traditional TELCO landscape.

In a tech company-like approach, DSP are (finally!) taking advantage of the connectivity footprint, data, know-how, skills, and geographic capillarity they have to refresh, reinforce and reinvent their business lines. They aim to create full-fledged telecom and technology solutions, leveraging their networks to enrich customer relationships, thus evolving from TELCO to TECHCO. Internet of Behaviour and Tactile Internet are now two spaces with many opportunities coming up from the advanced and zero-latency connectivity coupled with new engines that can be added, like Virtual Reality and the real internet of things.

Recognizing this, Altice Labs has been transforming itself for some time, anticipating this new era to build a new puzzle that combines applications into four major digital areas: digital business and operations, advanced connectivity, smart life, and industry digitization.

Once again, Altice Labs publishes InnovAction, the 7th edition of our technological magazine, where we highlight the work done in our R&D labs to ensure that Altice Labs contributes to the digital renewal that this TECHCO style demands and, as always, supports its customers toward the step beyond!

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

Alcino Lavrador
General Manager of Altice Labs

Editorial note

In their quest for evolution, telecom operators (TELCO) have been reinventing themselves for many years, from the days when the main business cases focused on critical infrastructure and connectivity right into the boom of digital services, content delivery, cloud providers, and so on. Now, the main trend is to evolve even further from digital service providers (DSP) into technology providers - TECHCO, reinventing, once again, their offer and value to meet the market needs.

Under the topic 'One step beyond!', the articles in this new edition of InnovAction present the demanding but exciting challenges ahead for TELCOS, giving some insights on Altice Labs' work to address the TECHCO journey:

- **The long and winding road to TECHCO:** an analysis of the drivers that push TELCOS to become TECHCOS, the technological enablers, and the challenges they face along the way.
- **How advanced connectivity is boosting the industry digitalization:** this article analyzes the evolution of communications towards a digital world and the technology roadmaps in Altice Labs' connectivity product portfolio.
- **Uncertainties on PON diffusion:** reflecting on the complex telecom industry evolution, this article analyzes the next-generation PON market and its driving forces. PON development investments must consider the different market vectors as well as the associated uncertainties.
- **An e-health use case enabled by private 5G, AR, and edge computing:** the merge of augmented reality with 5G and edge computing in the healthcare ecosystem will effectively improve execution time, satisfaction, and confidence in post-graduation surgical metaverse education and training. This article presents a concrete use case of this technological combination in remote cooperation between surgeons.
- **Space communications and applications – a huge potential to unlock:** this article overviews the satellite communications sector and the renewed enthusiasm motivated by technological advances, like 5G non-terrestrial network integration and its use cases.
- **How digital business & operations solutions are fostering a smarter life:** an analysis on the TELCO to TECHCO journey, the requirements and the innovations introduced, with particular emphasis on digital business and intelligent and autonomous operations solutions. Definitely, these will foster a smarter life for

the end customer and those who work daily to ensure that service delivery corresponds to the customers' requirements and expectations.

- **AR over GIS to make field interventions more efficient:** based on Altice Labs' Netwin AR app for FTTH proof-of-concept, this article highlights augmented reality technology disruption in improving the technicians' operational efficiency.

- **NOC automation, another step towards autonomous operation:** management, monitoring, and automatic action become crucial in the new paradigm of telecommunications networks, and this article reflects on the strategy CSP need to succeed in their transformation path.

- **Connected life: the path to a smarter ecosystem:** new services and agility, supported by solid partnerships, will foster new sources of revenue, and Altice Home is Altice Labs' offer to facilitate people's living by enabling an increasingly connected life.

- **Agrotech – sensing use cases:** with a practical example of IoT sensing technology for the banana crop in Madeira Island, we present a solution for more precise and sustainable agriculture in the agrotech revolution to meet the future demands for food in a more sustainable, efficient, and eco-friendly way.

- **Can we escape the Metaverse? Should we?:** to answer these questions, this article reflects on the concept of 'metaverse', what parts of it exist today, and what is foreseen that makes this concept a much-discussed game changer.

- **Digital health: current trends and applications on innovative care:** as a strategic approach to meet the need to provide health care to an increasingly aging population, digital technologies shape the future of global health. Medigraf and SmartAL, from Altice Labs' product portfolio, contribute to support this vision.

To wrap up, TELCOS face disruptive yet stimulating challenges towards the TECHCO evolution. Opportunities are certainly better for players who embrace disruption, re-imagine their network services capabilities, and drive growth. Altice Labs' product portfolio evolution is aligned with these requirements to boost Altice Group's ability to diversify further and build up Customers' and Partners' strengths for the benefit of all. Welcome to the seventh edition of InnovAction!

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Contents

DOI: https://10.57650/innovaction/2022.01

01 The long and winding road to TECHCO

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As new ecosystems emerge from the 'primordial soup' of cloud providers, hyperscalers, content providers, software providers, and TECHCOS in general, TELCOS are questioning their role, exploring ways to be an important node of that value mesh, and still be the commodity that holds it together.
This article explores the business drivers pushing TELCOS to act more like TECHCOS in the TECHCO space, identifies the technological enablers which could help them do it, and pinpoints the main challenges present along the way.

Keywords

TELCO; TECHCO; Digital Transformation; Softwarization; Virtualization

Introduction

All telecommunications operators were born and created equal: stand-alone, vertical and centrally controlled!

New telecommunications services used to appear a few years after a long period of international standardization and were then made available to customers, but only after a considerable period of heavy investments in networks and terminal equipment. For each new service introduced in the market, the telecom operators would create a new business and technical silo internally, from marketing and sales to engineering and operations, billing, and customer support. This pretty much sums up the story of the fixed voice and video conferencing services, telex, fax, mobile telephony, mobile video-call, and mobile data services which appeared in the 40s and up to the 90s in the last century. And these companies were called TELCOS.

Then came a new service that was in no way similar to the previous ones: fixed internet access, followed a few years later by the internet companies and the concept of platform businesses. TELCOS were suddenly confronted with a new paradigm of introducing services and conquering customers (or users) – a new internet service only passed through a rather brief and ad hoc standardization process and could be up and running with real users in only a few months, without any formal standardization, regulation, or compliance process. It only got worse when mobile internet access was generalized and brought with it the smartphone revolution!

As a result of the internet way of developing technology, services, applications, and content, internet companies and the new platform businesses were born exactly the opposite of the telecom operators: open, with a distributed control philosophy and building upon an ecosystem of technologies and partners, both internal and external, thus extremely flexible from its inception. And now these companies are called TECHCOS.

Things have evolved since the late 90s until today, positively for the platform businesses but not so well for the TELCOS! Today, the constant launches of new ideas of services and contents by digital platform companies have relegated operators to an even smaller corner of relevance, as seen by the end users. Clients perceive TELCO services as costs they must bear rather than solutions to their problems.

The recent cord-cutting movement [1], where people only require from their telecom operator broadband fixed or mobile internet connection while dropping all other TV or voice services, is digging an ever-increasing divide between the two businesses: telecom and platform/content.

But bad news never comes alone! Despite selling fewer and fewer paid services and content to end users, telecom operators are required, both by the market and regulators, to keep investing in their networks in order to meet an ever-increasing demand for broadband internet access services. All this is meant to support the bandwidth-hungry contents sold by the platform businesses and the thousands of public and private services now available online, as the result of a rapid digitalization of society.

The combination of the factors mentioned above reflects heavily on the stock market valuation of the telecom operators, as mentioned in [2]. Despite grossing practically the same revenue as the internet giants in 2020, the market capitalization of the combined 78 top operators (communications service providers - CSP) in 2022 was only about 20% of the former.

So, the problems are clear, but there should also be some opportunities and strategic directions for telecom operators or CSP in the present context, right? That is precisely what we will try to explore in this article.

We start by explaining the business drivers pushing TELCOS to act more like TECHCOS in the TECHCO space. Next, we identify the technological enablers which could help them do it, and then we pinpoint the main challenges present along the way. We conclude with some directions and examples of how the Altice group is addressing this subject.

Business drivers

A recent assessment from the Body of European Regulators for Electronic Communications (BEREC) [3] clearly counters the proposal of the European Telecommunications Network Operators (ETNO) to have content and application providers, such as Google, Amazon, or Facebook, paying TELCOS a 'fair share' that would compensate the costs that they incur in dealing with the traffic generated by these application providers.

Whether you agree or disagree with the proposal or the answer to it, this raises an important question: are TELCOS just providing the 'pipes' that deliver someone else's value? The markets seem to believe so. A recent study [2] mentions that, despite producing approximately the same revenue as the internet giants, TELCOS are perceived by the market as much less valuable, as **Figure 1** shows (wildly assuming that market capitalization is directly related to value perception).

Apparently, no one expects much more from TELCOS than plumbing for bit flows. Even some TELCOS themselves. And this is far from the glory of providing the new, exciting services and content that tickle the markets and make clients smile happily.

Mind that assuming the role of pure connectivity providers is a valid option, often neglected or dismissed by TELCOS. Commodities are by no means minor business players, and clearly, if you have both feet (and your head) on that game, it will certainly bring you good business

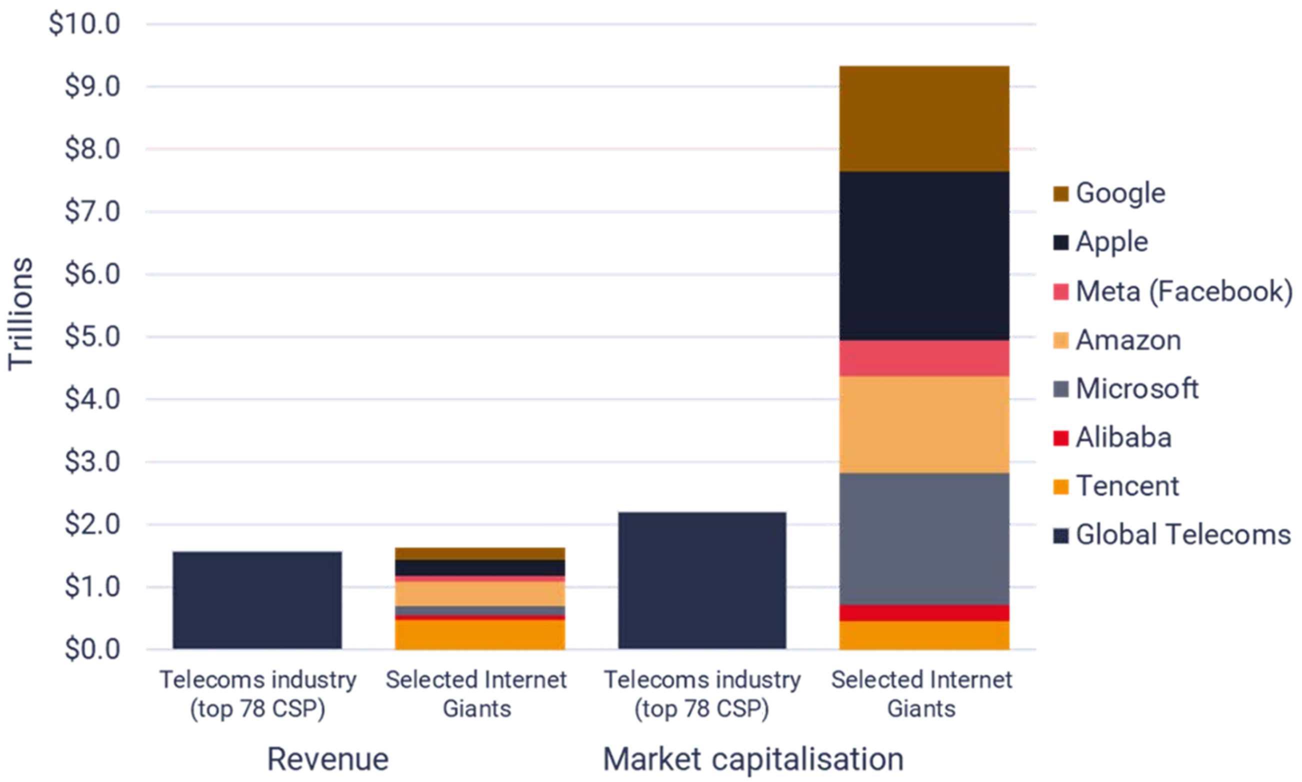

FIGURE 1 – Revenue (2020) and market capitalisation (2022), TELCO vs. internet [2]

opportunities and the trust of your clients. The downside is that this is a highly competitive, narrow margins, price-driven market where only the leanest and most efficient companies will survive.

This leaves TELCOS with another option: climbing the value ladder that leads from CSP to digital services providers – TELCO to TECHCO.

As stated before, TELCOS are very different from major internet/platform players, so trying to copy them does not make much sense. Many TELCOS have been learning that lesson the hard way, with problems like legacy systems to cope with, a regulatory scenario that seems unfair, and inadequate structures, only to name a few. Also, competing directly, although in some cases necessary, with some over-the-top services is probably not the best approach. Instead, an ecosystem approach seems to make much more sense. Why not work together with TECHCOS to provide valuable solutions?

That ecosystem already exists. It has been building up and now comprises actors that we can place in a few different classes [4]:

- **Cloud providers**, delivering cloud infrastructure and services across the world (AWS, Azure, etc.);
- **Content providers**, whose products can be aggregated in rich entertainment services;
- **Software providers**, representing many disparate sources of functionality, ranging from the traditional TELCO providers to all kinds of startups with high potential solutions;
- **Hyperscaler services**, like those of Microsoft Teams or Google Messaging.

Those actors, together with specialized companies from whatever business domains to address, are either too focused on specific aspects, lack the dimension, or don't have the trust capital to be able to provide end-to-end solutions and support them. From this point of view, TELCOS are in a 'sweet spot': they have long-standing relations with their clients, who trust them, and have the dimension, the structure, and the technological capabilities to join high-value players into higher-value proposals.

This means that if TELCOS can harness the complexities of each vertical, they are well positioned to assume a leading role. The same applies on the B2C side of the business: TELCOS benefit from the trust of their customers and can act as an intermediary payment entity for several different services, or the provider of networking and internet of things (IoT) systems, aggregator, and biller of several media platforms, to name a few.

On the TELCO side, network technologies like 5G will place TELCOS where they aren't yet: inside industries (including factories), and in critical public communications, on the roadside, in increasingly pervasive sensors and actuators everywhere. Communications keep the digital world together, and TELCOS are holding a large pot of glue.

Besides communications, business collaboration is leveraged by software-oriented approaches, with cloud and open API playing an important role, and clearly showing TELCOS that they should be leaving their shells to reach further, but also exposing more.

Notice that even to be able to survive as 'bit pipes', TELCOS will have to pay attention to these trends: not only will they have to be part of increasingly complex ecosystems, but network evolution will also push them towards technologically advanced solutions and digital transformation, anyway.

Inside TELCOS, business dynamics are changing and will change further, even at a financial level: on the one hand, network virtualization and the overall softwarization of networks are burdening TELCOS with high investment costs in common computing infrastructure at the edge of the network (CAPEX), on the other hand, support systems are increasingly scattered across public clouds and software-as-a-service

(SaaS) providers, as operational costs (OPEX). Having cloud-based support systems (and their interoperability) is already enabling the orchestration of best-of-breed components, while the strong investment in computing infrastructure at the edge of the network is likely to provide the basis for another reliable source of income in the future: edge computing.

Technological enablers

For a long time, TELCOS looked at IT from the single perspective of management information systems. Computers, software, and all the related processes would be kept in the domains of the so-called support systems. In this scope, solutions have smoothly been evolving through trends like virtualization and the cloud, with clear gains cashing in from that evolution. Today, it is the very network that is capitalizing on the benefits of computing-based approaches [5]. Network softwarization is really happening... fast. And with it:

- Network functions are being virtualized to computing workloads running where and when they are best suited - let's call it network function virtualization (NFV) and TELCO cloud to include the buzzwords. Software-defined networks provide the flexibility necessary to disaggregate the hardware-based user plane from the software-based control plane, thus guaranteeing immediate interconnections between these functions.

- Network analytics have started to rely on artificial intelligence (AI) to explore a bounty of available data, raising networks' self-awareness and feeding actuation mechanisms on the path to zero-touch loops, where networks organize and heal themselves, reducing operation costs.

- DevSecOps, continuous integration and delivery, and agile project methods borrow agility from the IT ecosystems, making concept-to-market times a fraction of the traditional TELCO offers.

- Finally, and very importantly, the definition of open API, both across network functions and towards management and control, create the conditions for the existence of a much richer ecosystem of network function providers, countering vendor lock-in and enabling the construction of complex solutions involving components from various players to fit the needs of customers, not only within the network/TELCO space but including multiple platforms from multiple players of a broader ecosystem.

One good example in the path of network softwarization is 5G. The very specification of the 5G Core by the 3rd Generation Partnership Project (3GPP) [6] is fundamentally different from all the former mobile generations: besides defining functions, interfaces, and protocols, it now specifies a service-based framework, well suited for a software-based, disaggregated approach to the network nuts and bolts. To be more specific about some 5G-related aspects that enable a new approach from TELCOS:

- 5G has a clear focus on industries and digital life, making the mobile network capable of supporting use cases like ultra-reliable low latency communications (URLLC) or massive machine-type communications (mMTC). This addresses a space where many industries and other organizations tend to deploy and explore their own purpose-oriented network, because of lacking offers from operators.

- Combining URLLC and mMTC with network slicing (i.e., the capability to deploy feature-specific, virtually isolated networks, ranging from in-building to cross-country, either single or multi-tenant) enables the creation of targeted offers to all kinds of businesses and industries, addressing a plethora of new use cases related to the pervasiveness of IoT, e.g., vehicular communications or smart cities.

- One particularly interesting possibility is the creation of 5G private networks, ranging from network slices of the public network infrastructure to completely private network deployments at the customer's premises.

One valuable capability that TELCOS can offer is computing capacity at the edge of the network, close to their clients [7]. This serves their highly virtualized network functions, but it is also a valuable asset that can be traded with both clients and other service providers. For example, to enable the offer of low-delay services like augmented reality (AR), computing cannot be placed in a data center halfway across the world. Also, many companies and individuals simply won't accept that their data is kept and/or processed in mistrusted places. This is an opportunity that can be explored by TELCOS, in collaboration with cloud operators and other players, together in a cloud-enabled environment that offers unprecedented possibilities.

Access networks, which are the most valuable asset for most TELCOS, will always play a key role as they continue to evolve to richer, more convergent connectivity driven by new fixed and mobile technologies, namely full fiber fixed networks and 5G mobile networks, and in a path to convergence, largely determined by software disaggregation and overall network softwarization.

Traditionally, one of the reasons why TELCOS have limited-service offers is because they are not prepared to deal with the complexity that expanding their offers would bring. What many of the business and technical evolution challenges represent is exactly an extreme increase in complexity, albeit somewhat mitigated by novel approaches to support systems. There, the role of AI is key in providing the automation that will be needed to keep the operations manageable and tendentially leaner. Self-organized, self-optimizing, self-healing networks are leaving the science-fiction chapter to integrate the new TELCO/TECHCO story, and they really have to. Otherwise, networks will just be too complex to run.

Challenges

According to a survey in a TM Forum report [8], one out of three of the companies responding stated that they are committed to becoming a TECHCO, while most of the other two-thirds said they saw this migration to TECHCO as strategically relevant for their organizations. But this transformation is one with many challenges, which could be broadly classified as:

- Technological;
- Business models;
- People and culture;
- Knowledge and skills;
- Legacy IT and applications;
- Investment and financial model conversion.

In the following sections, we will address each one of those challenges in more detail.

Technological challenges

Before addressing the platform business, TELCOS need to prepare their networks and systems to be 'the platform'. Access, backhaul, and fronthaul networks must be harmonized, simplified, and automated, integrated with single network cores. Open network service API need to be provided. IT systems will need a new architecture capable of providing services both internally and externally, namely the capability to monetize any type of service or content. Strategic cloud adoption decisions need to be taken: operator cloud, IT cloud, private, public or hybrid? As the importance of data will be crucial for the future TECHCO, all these networks and systems changes need to have data and analytics as one of the strategic pillars.

Finally, running an open network platform presents extremely high cybersecurity risks, and therefore TELCOS need to create their platforms secure by design.

Business models

Traditional TELCO business models are based on selling their own communications services and reselling products and services from third parties. In some cases, operators also sell and deliver professional and managed services.

Changing into a TECHCO and therefore running platform business models like network-as-a-service or selling combined TELCO+partner services through an online marketplace implies, among other things, a solid commitment to build and maintain a vast ecosystem of suppliers, integrators, and customers. Finding and engaging with the right partners will be one key challenge of the future TECHCO.

People and culture

Traditionally, internal staff at TELCOS have a culture of working closely with a small group of equipment vendors, producing requirements and preparing requests for proposals (RFP) for systems and software acquisition, and then running very long transformation projects, following a waterfall model. R&D investment is comparatively meager, and most of the TELCO-focused R&D is performed by the vendors supplying systems to TELCOS.

People will need to shift their way of working into a flexible, open, agile, and multi-partner paradigm. Most processes will be automated and will free people for more customer and partner-oriented jobs, which will require a lot of training and coaching.

Knowledge and skills

Dealing with an open, multi-technology ecosystem of partners and systems, as is traditionally the case with platform businesses, is very different from dealing with vertical single-vendor telecom systems.

TELCO staff will need to acquire a new set of skills, namely in the domain of cloud software engineering. They will need to be able to integrate new partner apps and contents with their own API in only a few days or even hours.

Bringing a new industry vertical solution into the TECHCO platform will require not only the knowledge of the platform but also the specific vertical know-how, probably brought through a specific partner.

It is expected that the journey to TECHCO will require major reskilling of internal TELCO staff and significant new hires of people with the required skills.

To become TECHCOS, TELCOS will need to recover much of the engineering and innovation capabilities that were progressively handed over to telecom vendors throughout the years.

Legacy IT and applications

Technology is quickly promoting the evolution of networks and support systems into a single digital reality: network and management 'machinery' working together over a common infrastructure. But TELCOS carry a heavy technological legacy. Although every new network generation may be simpler than the previous, it will always add to the overall complexity because the new rarely eliminates the old; it only creates more interworking challenges. On top of each new network generation, a new set of operations support systems will be built, and probably also some new business support systems. This is a major challenge to modernization as it hinders the simplification needed as a first condition to make TELCOS leaner.

Investment and financial model conversion

We could not close this section without discussing the financial implications for TELCOS to become TECHCOS, as this might be the main decision factor for most of them.

For a long time, TELCOS have been handing in much of the technical mastership of their business to a few large technology providers. Regaining control of many technological aspects is essential to being able to play a key role in the new ecosystems emerging from the 'primordial soup' of cloud providers, hyperscalers, content providers, and software providers, to respond to different business verticals. This will require investment.

To become a TECHCO, TELCOS will need to invest in the conversion of their networks and systems into a digital network platform. Then they will need to invest in automating most of the repetitive tasks which were previously done manually. Along the way, they will have to reskill their business and technical staff, for the new platform business models and supporting systems. Hiring software engineers, cloud engineers, data engineers, data scientists, and AI experts will be necessary too. Traditionally low investment in R&D will necessarily have to rise if the new TECHCOS want to have a differentiating platform offer built with other software companies.

Another TELCO to TECHCO impact under the spotlight today is the implied increase of OPEX costs through the conversion of traditional CAPEX costs, as is the case when you move from in-house systems to public cloud licenses and other software licenses and hire specialized services.

All these costs may have a strong negative impact on the newborn TECHCOS' EBITDA, which is an extremely relevant KPI for investors. We suggest a further reading of [8] for an exhaustive discussion on this subject.

Conclusions

The basic options that TELCOS have to make for their future are set: commodities or TECHCOS. The former means doing business in a context of fierce competition, where low margins hinder investment capacity, a highly regulated market limits options, and the business model can only be supported by a large number of clients, which are constantly coveted by competitors. The latter offers wider possibilities at the cost of playing a game that is uncomfortable to the traditional TELCO: being part of a dynamic and complex ecosystem, working with other companies, and specializing in software products and custom vertical solutions.

In either case, but especially for a TECHCO path, there are many business and technological opportunities and a major challenge: changing the organization itself.

On their way to becoming TECHCOS, TELCOS are now on the verge of being able to join their capabilities with those of other players in various ecosystems. The TELCO with a limited offer of take-it-or-leave-it services is now giving place to a tailor that cuts through the needs and expectations of each vertical to collaborate in providing the best-fitting solutions. The promise is enormous. The challenges are, too.

But the future will surely have more colors than just black and white. Some TELCOS are taking a mixed and phased approach in their migration path by first setting up extremely efficient bit pipes while at the same time setting-up joint ventures which look a lot like TECHCOS.

To conclude, what does this TELCO to TECHCO migration mean in simple, technical terms? Ultimately, it's all about being more flexible, mastering the software development and integration life-cycle tools and platforms, and applying agile project methodologies. Basically, being more like a software company, running a platform business model where the platform is the TELCO networks and systems, open externally through API, and collecting huge amounts of data on products and customers. All this from within a large ecosystem of partners, suppliers, and customers.

As an organization, Altice is set for this transformation. Programs like the Altice Group IT Evolution (AGITE) or Kairos, an operation-wide people reskilling, and at the network level, the bet on passive optical network (PON) technologies to get a single fixed network technology for every application are questioning and challenging the status quo and defining a path towards the future.

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DOI: https://10.57650/innovaction/2022.02

02 How advanced connectivity is boosting the industry digitalization

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Optical fiber, together with mobile and non-terrestrial networks, make up the fabric that is supporting the evolution of communications towards a digital world. Altice Labs' connectivity product portfolio and the corresponding technology roadmaps are well aware of that and are focused on giving the proper technical answers to the challenges that lie ahead for the communications networks of our partners and customers.

Keywords

Advanced connectivity; PON; 5G; O-RAN; Satellite

Introduction

The recent COVID-19 pandemic and current geo-political security concerns have been anticipating and demonstrating that communications are far beyond 'commodities', showing up day by day with ever more technical, social, and political impacts on our everyday lives. Today, communication disruptions hold the same, or even higher, negative user impact than failure on other critical services such as water and energy supply.

Optical fiber is the basis of present worldwide landline, wireless and mobile communication networks. It is thus stated as one of the main drivers for the digital revolution, which is still ongoing worldwide.

As a complement to the existing terrestrial infrastructures, satellite communications and non-terrestrial networks are also getting market attraction and pointed as a critical complement to hybrid communication infrastructures ecosystems focused on the end user, whichever the end device and its geographical positioning.

Altice Labs' connectivity product portfolio and corresponding technology roadmaps have been focused on giving the proper technical answer to the existing and upcoming communication challenges of our partners' and customers' networks, as described next.

Network infrastructure impacts

After being installed on long-haul and high-capacity landline and submarine cable connections, today's fiber optic communications have become closer to the end customer by further being massively deployed over access networks [1]. Distances are covered from the service provider's central office up to several service delivery points (e.g., homes, offices, cell sites, industry, institutional sites, etc.), turning up as significant investments. This fact only finds its historical parallel over legacy incumbent copper and cable massive investments that took place decades ago and have reached countrywide connections. Public and private incentives and initiatives, along with proper regulation, are currently undergoing to extend field fiber connections within urban centers and along rural areas. Wholesale business models and sharing of the infrastructure among several service providers are speeding fiber deployment and, thus, strongly contributing towards economic growth.

Passive optical networks (PON) are a very cost-effective solution to overcome classical issues related to distance range, noise immunity, capacity, latency, power efficiency, and quality of service, especially when compared with other legacy twisted copper pair and/or cable communication technologies [2]. PON allows sharing the same fiber infrastructure among all customer segments, making it ideal both from technical and business perspectives. Because of that, today's massive PON deployment allows existing and new industry and economic entrants to benefit from unprecedentedly fast and reliable communications at a very effective cost, covering homes (retail), businesses and enterprises (wholesale), governments (institutional), and individuals (personal), as depicted in **Figure 1**.

With increased throughputs and capacity, actual mobile networks also need more cell sites to cover the same geographical areas. The worldwide massive deployments of optical fiber at the landline access network have also set a solid communication backhaul for the mobile radio access networks (RAN) [3]. Nowadays, the geographical coverage and distance range of PON infrastructures are translated into high-capillarity mobile services. Therefore, mobile networks also rely on these same PON infrastructures to support the backhaul, midhaul, or even fronthaul decentralized architectures.

5G networks are often based on small cell deployments with a special focus on specific industry verticals, where local environment connections take maximum profit of extremely low

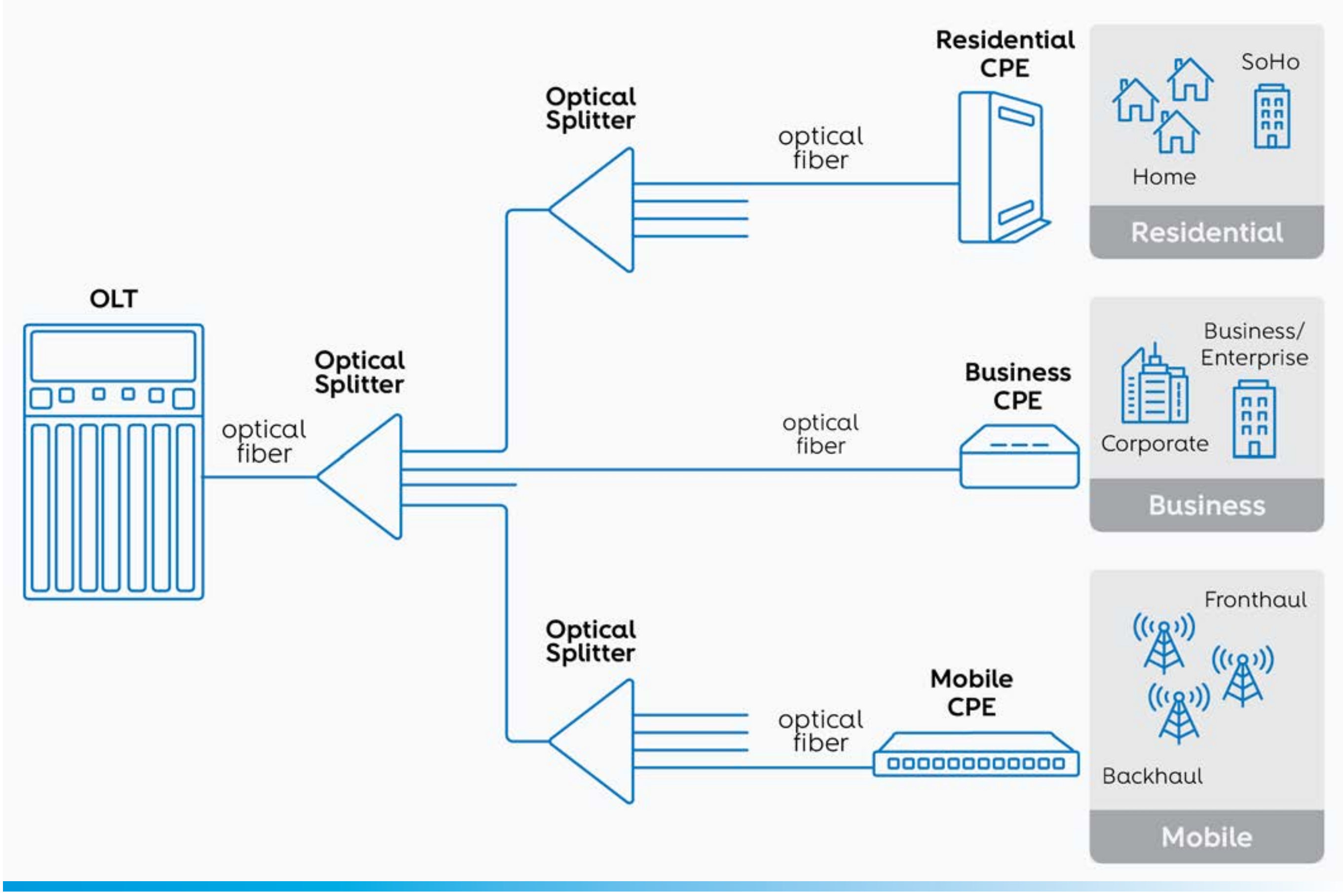

FIGURE 1 – Basic PON architecture

latency as well as higher capacity throughputs. The Open Radio Access Network (O-RAN) Alliance [4], a forum composed of the most relevant market players (vendors, telecom operators, and R&D institutions), boosted the development of a large variety of solutions, most of them turning dedicated hardware functions into software pieces able to run on top of commercial-off-the-shelf (COTS) hardware [5]. That relevant fact has brought a decentralization of the technology along the market and the network itself, showing up as a real opportunity for new entrants to experience technology advantages that, in the end, will be able to have a significant impact on local and global economies.

As a complement of the landline and mobile networks, low-orbit satellite communications are also emerging as a highly reliable solution for service continuity over terrestrial dark zones, not only for voice service but also for broadband, together with new dedicated services (e.g., autonomous driving, defense applications, environment watch & surveillance, etc.). Those non-terrestrial communications are currently being boosted by several private and public entities. The ease of access to satellite technology, together with new tools for cost-efficient production and manufacture of the components, has again attracted the attention of the telecom sector to complement land and mobile network environments. The specific use case of a satellite backup connection (e.g., catastrophes situations) is one of the most relevant scenarios where low-orbit satellites can have an immediate impact. Several other terrestrial-space hybrid 5G implementations are being envisioned to mass deploy 5G and upcoming 6G technologies at a much more efficient cost. Those studies will give rise to new industry opportunities and corresponding delivered services that will strongly impact our lives.

Service impacts

The aforementioned new network communication capabilities and foreseen technologies have been drastically shaping industries of a broad spectrum of sectors, replacing traditional ways of getting things done with faster and decentralized procedures and methodologies, significantly optimizing resources, lowering costs, and reducing ecological footprints.

Remote work

Several industries clearly benefit from remote work, such as software and IT, accounting and finance, customer and support, education and training, marketing and sales, and design and multimedia, to name a few of the most relevant ones. Team members can truly cooperate no matter the physical distance, avoiding unnecessary costs and wasting time (**Figure 2**).

As unlikely as it may seem, other industries like engineering and construction may also benefit from having several tasks remotely performed (e.g., project design, project management, purchasing, and supply chain). That same scenario can also be applied to many other industry segments with relevant positive professional and social impacts. Such was only possible due to the consistency and reliability shown by today's fiber infrastructure, which was put to the test and succeeded during the recent pandemic.

Apart from remote work, other specific industries are expected to benefit enormously from the new communication networks. Healthcare, automotive, and defense use cases are just some of the most paradigmatic examples.

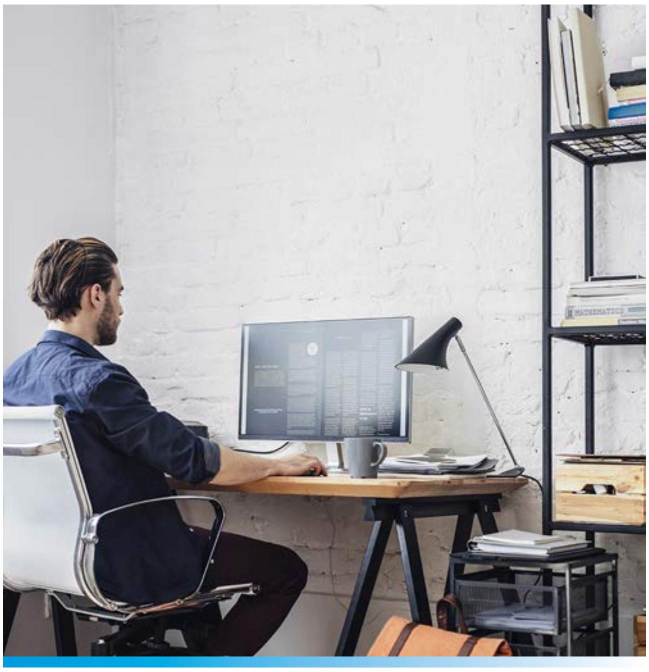

FIGURE 2 – Remote work

Healthcare

Hospital beds are often busy with long-term patients that do not exactly benefit from staying longer at the hospital, consuming significant resources, often critical to attend to other patients. Those same patients may now be transferred and be in the comfort of their own homes, being real-time monitored, followed, and diagnosed by medical staff, as shown in **Figure 3**.

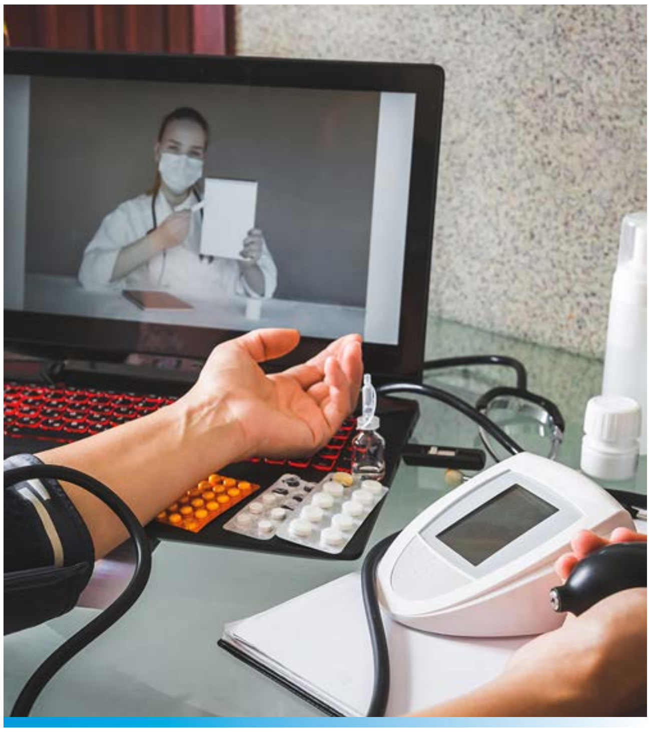

FIGURE 3 – Patient remote monitoring by using Wi-Fi and PON home access

Likewise, highly skilled doctors may remotely assist other medical colleagues in real-time interventions. Healthcare infrastructures are being prepared to take the most from the new existing high-speed and low-latency communication capabilities, also allowing full remote medical interventions in a future that is not so distant. Local instrumentation will be responsible for implementing the 'local physical hand' management, and therefore healthcare device materials industry should follow along, as seen in **Figure 4**.

FIGURE 4 – Remote-assisted surgery

Furthermore, healthcare information from millions of patients lies in high-capacity remote databases. That information needs to be constantly, immediately, and symmetrically accessed and available on-site by medical and administrative staff with a critical impact on service level and quality to be delivered to all end users, us.

Automotive

Automotive is among the industries that take more from actual and future communication networks' technological enhancements. We all want to access our voice and broadband services when traveling. However, expectations are even higher having the autonomous and remote driving concepts on the target. A huge amount of information needs to be available in the vehicle cockpit, not only related to vehicle information, like sensors, actuators, and cameras, but also information coming from outside of the vehicle (e.g., from other neighbor vehicles and the roadside infrastructure).

On the trend for remote driving, exemplified in **Figure 5**, where various automotive market players are also putting in some relevant effort, the end-to-end connection between the vehicle and the driver shows several challenges. Extremely fast, secure, low-latency, highly resilient, and continuous communication services must be granted and cannot be harmed in any part of the communication process.

FIGURE 5 – Autonomous and remote driving

Current and updated mobile 5G technology, as well as its subsequent mobile versions, should give the technological answer to these new service challenges.

Industry

Aligned with the technical and digital transformation, the industry, as a whole, has been drastically changing and benefiting from key resource optimization. Remote work, real-time remote control, and machine-to-machine communication between factory floor robots (see **Figure 6**) may also significantly rise production rates, thus increasing the corresponding profits.

Defense industry

In the defense industry sector, communications need to show unprecedented levels of security and resiliency to face cyber-attacks as well as attacks on traditional infrastructures in today's hybrid conflicts. Network redundancy, disaster recovery mechanisms, and programs need to be in place and aligned with other new upcoming technologies, such as quantum communications, to make defense network communications more effective and secure to play a significant role in the defense industry's future.

When in conflict, the continuous communication between the lead and the civil population (relying

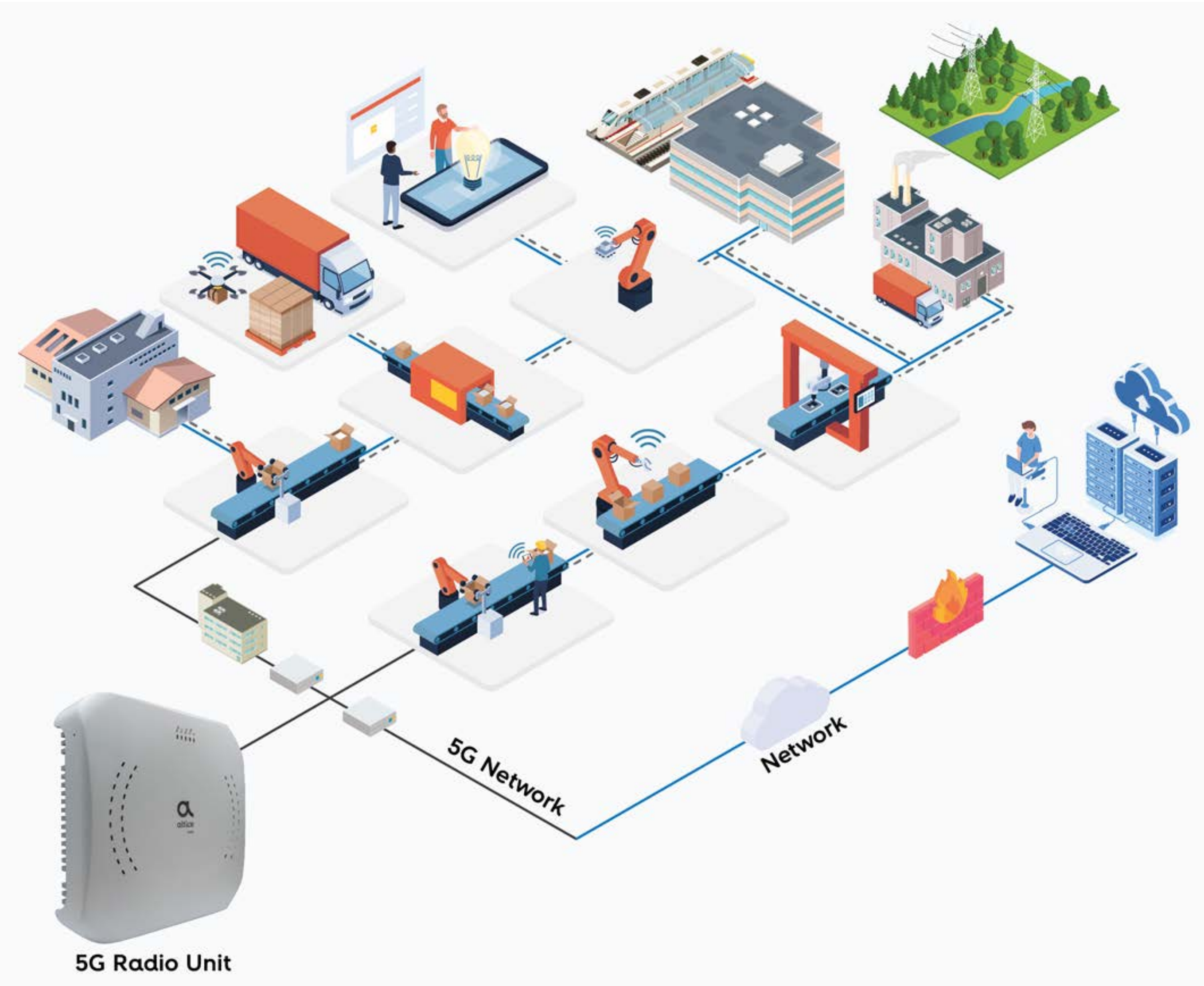

FIGURE 6 – Factory floor benefiting from 5G deployments

upon civil telecom infrastructures) has been revealed as a key element in the course of a war, and that was one of the main lessons from the recent conflict. There is an inherent and relevant motivational and psychological impact on that communication that cannot be neglected during a conflict.

On the other hand, technology has drastically changed war machines as well. Joysticks and drones are today as popular as shotguns and missiles. Data communication flow needs to be instantaneous and, most of the time, using the existing civil communication infrastructures. The impact of social networks on those scenarios is just an example of reliable and resilient civil communications throughout the war (see **Figure 7**).

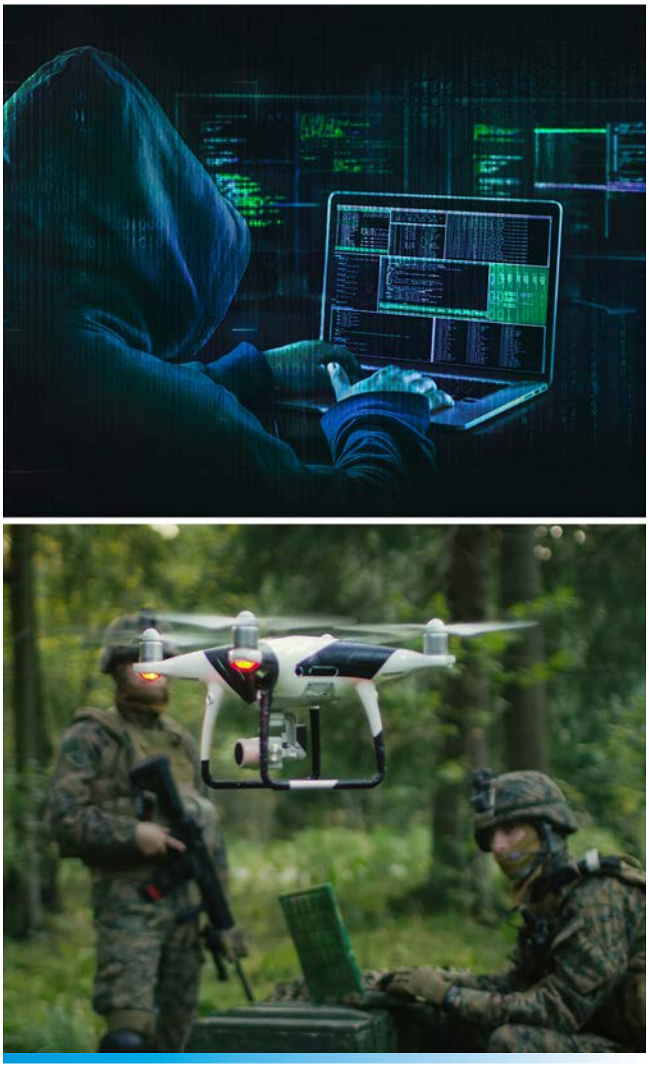

FIGURE 7 – New hybrid war

Low-orbit satellites have also demonstrated to be of critical relevance in high precision and real-time imaging of the world geography, as well as replacing landline and mobile civil and military communication during the conflict. Communication satellites and related industries are nowadays a real asset in the resiliency of voice and broadband services worldwide. That market is expected to grow in the short term to complement civil and military communications all over the world.

Conclusions

Altice Labs is aware of the new technological needs and has been working to address them, with a connectivity portfolio [6] comprising products and services that fit the key topics addressed in this article. Altice Labs' DNA is to continuously pursue solutions that address our customers' needs while evolving to face future connectivity challenges with significant impact on industries and the global economy in general.

With a complete PON portfolio, Altice Labs has been field-deploying and evolving fiber-based communication services around the globe. Carrier-grade solutions have been delivered, showing higher end-user bitrates and performances to address residential, business, and mobile market segments.

In what concerns the end user, Altice Labs' customer premises equipment (CPE) line of products intends to take advantage of the high-quality services delivered at the customers' premises. Currently, Wi-Fi is the most popular wireless access technology and is also embedded in Altice Labs' fiber gateway equipment family. From Wi-Fi 5, reaching today's Wi-Fi 6E, and looking forward to the upcoming Wi-Fi 7, these CPE are able to unlock entire connectivity capabilities up to the end user.

In parallel, over the past few years, Altice Labs has invested in the development of a 5G solution.

Taking advantage of the O-RAN architecture, this solution has been developed with a particular focus on the synergies with PON architectures, targeting fixed wireless access (FWA) as well as the fast-growing 5G private network vertical market. These solutions are expected to greatly impact on industry digitalization over the next years.

More recently, also earth-space communications solutions are being addressed at Altice Labs in order to complement the product portfolio with a non-terrestrial communication system, able to integrate future commercial hybrid communication networks where land, wireless, mobile, and space are orchestrated, looking forward to a full continuity and connected network.

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DOI: https://10.57650/innovaction/2022.03

03 Uncertainties on PON diffusion

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The telecom industry evolution is a complex process, marked by the interactions between scientific advances and market demands. Being no exception, the next-generation PON market is driven by the demand from end consumers for more bandwidth or applications, being influenced by technological advances in optical technologies and the constant launch of high-speed electronics that allows it.
PON development investments must consider the different market signs, such as the technological adoptions by the end-users, other telecom technologies, the mobile market, and the Wi-Fi market, as well as when and where to do it.
All those vectors are full of uncertainties of all kinds, namely technological, infrastructural, political, and competitive/ concurrency, being those analyzed in this article.

Keywords

Telecom; Markets; Industry; Technology; PON

Introduction

The telecom industry evolution is a complex process marked by the interactions between scientific advances and market demands.

The technology changes the inherently stable economic system environment, where careful and conservative planning aims to assure business longevity, to ones where chaotic change can cause even the most solid to fall.

Most decisions that technical managers make comprise specific markets, demand behavior, availability and quality of suppliers, regulation, policy, and legal constraints, as well as the competitive environment. Likewise, the changes in the social dimension, user practices, and societal behavior also play an important role.

Technology evolution and technology targets

The next-generation passive optical network (PON) market is not only driven by the demand from end consumers for more bandwidth or applications. The market itself is influenced by technological advances in optical technologies and the constant launch of high-speed electronics that allows it. The behavior of technology developers, as well as the behavior of organizations in providing more and more technology to sell, causes final consumers to despair. At the same time, the political actors themselves, as well as the standardization bodies, often cause instability in the market. The constant development of new standards with higher-speed technologies makes the market want them, even if it does not need them currently, except to meet possible future requirements. Technology developers end up creating problems with the demand for greater bandwidth to sustain their markets without the need for them.

Next-generation PON (NG-PON) technologies are starting to be deployed to support nonresidential customers and applications, providing additional sources of revenue over the same fiber-to-the-home (FTTH) network. It is expected that NG-PON equipment will be used in enterprises, smart cities, campuses, and xHaul transport applications with the increasing availability of 10G-PON optics and equipment and the future 25GS-PON and 50G-PON. As older generations of PON technologies, such as gigabit PON (GPON), were used for nonresidential applications, where limited bandwidth was a constraint, with NG-PON this can be overtaken. Residential was not the focus of the NG-PON technology, but the longer-term effects of the pandemic on society, such as changes to individuals' working habits, reduced international travel, and the rebalancing of business activity towards digital products and channels, are posing opportunities for the 10G-PON.

The pandemic has highlighted the importance of home broadband, so operators should work with governments to deliver the necessary new infrastructure. The enterprise market has been permanently altered, and operators must re-position their product portfolios to support changed working practices and business priorities.

Some major markets for technological evolution are presented next.

Residential

Unprecedented demand generated by the pandemic, more people working and studying from home, as well as increased virtual social communications, advanced video gaming, smart home applications, and e-health, are pushing the current residential PON technology to its limits, offering opportunities to the NG-PON bandwidth.

The importance of reliable broadband for households in this new world cannot be overstated, and this will be reflected in public policy.

Enterprises

10G-PON enables service providers (SP) to offer symmetrical bandwidth services, such as 1Gbit/s and higher, versus the older PON technologies generations. Higher symmetrical bandwidth expands the market opportunity for 10G-PON deployments, spreading from residential and small and home offices (SOHO) to bigger small and medium-sized enterprises (SME).

Several SP are building, expanding, and/or upgrading their FTTH PON networks to NG-PON to support new SME customers, a new customer segment. PON enables the efficient use of fiber to support clusters of SME, such as those in central business districts.

SP typically use point-to-point fiber to support business customers, and sometimes fiber unavailability happens due to customer growth along with increased bandwidth demand from existing ones. Other SP want to move SME onto less expensive infrastructure, such as PON.

One reason for using PON is simply fiber efficiency. PON can support multiple SME on the same fiber strand, thereby saving fiber usage and minimizing the footprint in the central office (CO).

A major challenge to the reuse of PON for SME services is organizational, where different departments are responsible for supporting residential versus SME customers.

The use of PON for SME is leading to new product innovation. Several vendors are adding to the PON equipment capabilities of switching and routing as well as wireless.

The importance of reliable broadband for SME in this new world cannot be overstated, and this will be reflected in public policy.

Smart cities

SP are supporting municipalities as these local governments roll out smart city services. While we often associate smart cities with wireless connectivity, several smart city applications require significant symmetrical bandwidth, such as public safety video surveillance. Concurrently, municipalities are deploying smart city plans that include cloud-based platforms to allow interactions with residents and businesses. 10G-PON is being deployed to support municipalities as they use the cloud to support more e-services.

xHaul

PON has been used to support small cell backhaul for many years, but older generations of PON had bandwidth constraints. 10G-PON can fulfill the higher bandwidth wireless backhaul requirements expected from dense 5G small cell deployments. PON's point-to-multipoint topology enables fiber asset efficiency versus point-to-point solutions. This efficiency becomes vital when planning to implement significant volumes of small cells. Alongside, less space is needed in CO when PON is used versus a point-to-point fiber.

PON is just one of many solutions for wireless backhaul. It is not expected the use of PON to become the dominant solution, but it has several advantages and should be evaluated alongside alternatives as new PON generations with increasing bandwidths are coming.

The use of 25GS-PON to support 5G wireless mid-haul and backhaul, as well as future 50G-PON to support 5G fronthaul, is gaining mindshare.

In evaluating PON for xHaul applications, there are several different business models and strategies that should be considered:

- For SP that offer both wireless and wireline services, using existing FTTH PON networks can save time and money. FTTH PON equipment can be reused to support wireless backhaul by adding and/or upgrading to 10G-PON in the CO and the future 25GS-PON and 50GPON.
- SP without FTTH PON can adopt unified access network planning, deploying PON for both residential customers and wireless backhaul.
- Several integrated and wireline-only SP wholesale their PON services to support wireless backhaul traffic for other operators. This model enables SP to achieve a faster return on investment due to multiple revenue streams.

Ethernet and passive optical LAN

Campuses, such as airports, manufacturing facilities, financial institutions, universities, and hotels/resorts, often operate internal communications networks. Traditionally, these local area networks (LAN) consist of switches and routers where devices are connected using copper-based cables, such as Cat5 or Cat6. The adoption of passive optical LAN would require the replacement of electrical cabling with optical-fiber cabling, but the replacement can be done fragmentary, such as focusing on a particular building or facility, or can be campus-wide.

Typically, the business reasons for moving to passive optical LAN are related to bandwidth demand among campus-based network users, along with increased cloud-based usage. Cloud-based services, including software-as-a-service (SaaS), infrastructure-as-a-service (IaaS), and platform-as-a-service (PaaS), are being adopted by enterprises throughout the world. These cloud-based services require more bandwidth and symmetrical bandwidth for campus users.

There are many advantages to a passive optical LAN compared to a traditional copper-based LAN. These advantages include:

- Greater bandwidth and ease of bandwidth upgrades—support for up to 10G per end-user when 10G-PON is deployed. In addition, with passive optical LAN, IT departments can decide which users or facilities need higher bandwidth rates.

- Potential CAPEX and OPEX savings, including power and space—an optical LAN uses less cabling, fewer racks and switches, and less power than a traditional LAN.
- Passive optical LAN can support large campuses within 20 kilometers and beyond.
- Reliability, redundancy, security, management. The underlying optical distributed network (ODN) can be designed to provide redundancy if necessary. PON infrastructure is considered highly secure. It is resistant to interference and meets the security requirements of governmental defense agencies. Passive optical LAN solutions include end-to-end elements and provisioning management tools.

Energy saving and environmental protection

The actual economic scene benefits ecological and low power consumption solutions due to resource exhaustion, global warming, and protecting the planet. Expectations about the increasing energy consumption levels associated with the growing demands for broadband services are raising concerns and calling for the implementation of energy-efficient equipment and strategies. The latter is gaining growing attention, driven both by ecological and economic values. The need to achieve significant breakthroughs in network energy efficiency requires hardware enhancements to be integrated 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 mainly to three crucial factors:

- reducing operators' OPEX;
- reducing the network contribution to greenhouse emission gases;
- legislation.

Next-generation equipment should be as efficient as possible, allowing minimal energy cost per bit. Equipment is the one that effectively consumes the power in passive ODN.

A code of conduct (CoC) from the European Commission Joint Research Centre [1] sets out the basic principles to be followed by all parties involved in broadband equipment operating in the European community in respect of energy-efficient equipment. In the United States, the Energy Star program identifies and promotes energy efficiency for small network equipments.

Optical network units (ONU) are the ones that effectively consume the power in passive ODN. Although the customer premises power does not account for the operators' costs of OPEX, it could be misleading not to consider this factor in the network design trade-off, and thus, not considering the ONU power consumption when deciding to implement a particular technology [2].

Uncertainties related to the development of PON technologies

Different types of uncertainties are more relevant depending on the phase of dissemination and the role of stakeholders. Uncertainties can have several origins. We follow the typology proposed by [3]. Thus, the main uncertainties affecting the PON technology sector relate to the technology and PON infrastructure progress, demand trends, government policies, competitiveness,

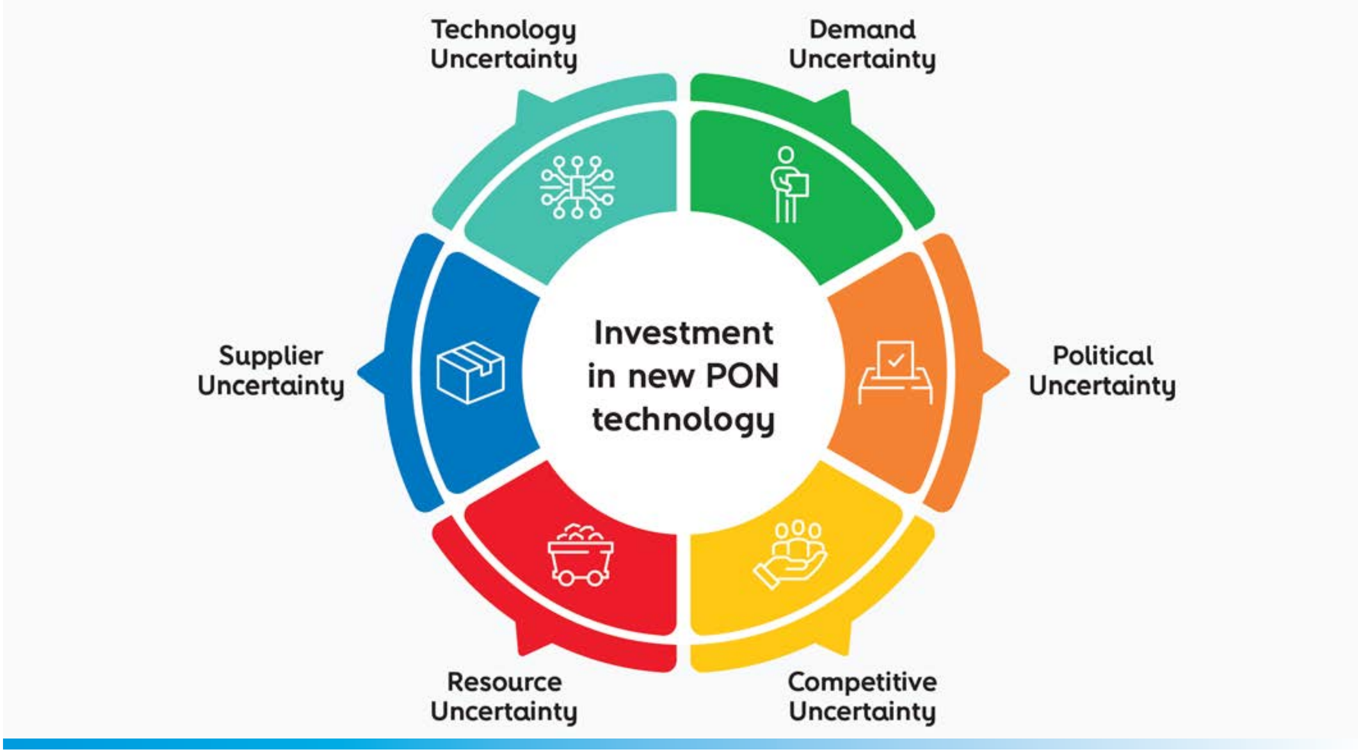

FIGURE 1 – Identification of uncertainties in investment in new PON technologies

the existence of physical resources, and supplier uncertainty (see **Figure 1**).

Technological uncertainties

Technological uncertainties have a major impact on the investment in PON technologies.

The unpredictable evolution of competing technologies amplifies uncertainties and impedes the penetration of a specific technology in the PON market. The technical characteristics of the different technologies evolve thanks to learning [4], the speed of improvement, and the arrival on the main market [5]. All this constrains the possibilities of each new technology to replace the older ones.

The emergence of a new PON technology, such as XGS-PON, NG-PON2, 25GS-PON, or 50G-PON, has an impact on the proliferation of GPON due to several factors. From a CO point of view, a telecom operator has to decide if:

- It should continue investing in GPON or delays its investment to gain an advantage using the new PON technology;
- The actual CO has the physical capacity to put in more new optical line terminals (OLT) or substitute the old ones;
- The actual CO has the physical capacity to accommodate coexistence elements (CEx);
- The actual bandwidth capacity is enough for the existing and future users, or will end users need more bandwidth;
- It will support over actual technology more types of services, or it will require more bandwidth and functionalities, for example, support of mobile backhaul;
- New PON technology has the same power consumption and temperature working range as the actual;
- New PON technology is profitable. New adopters generally pay more for more recent technology.

From a client point of view, a telecom operator has to decide if:

- Continue investing in GPON or delay its investment to gain an advantage using the new PON technology;
- Maintain the same type of terminals or invest in new ones: single-family units, fiber gateways, and mobile backhauls;
- Want several technologies over the same terminal, as Wi-Fi (numbers of antennas, type of Wi-Fi), internet of things (IoT), number of ports, type of ports (1GbE, 2.5GbE, 10GbE), radio frequency (RF);
- Terminal speed: XG-PON1, XGS-PON or NG-PON2;
- The new PON terminal is 'low cost'. New PON terminals have a higher cost due to the support of new higher-speed optics.

Not only is speed enough for a new PON technology to penetrate and diffuse in the market, but also functionalities, capacity to support multiple technologies over it, density, power consumption, thermal working range, price, manufacturing capacity, and manufacturing delivery capacity for the target market.

Uncertainties about the evolution of PON infrastructure and demand

The establishment of a PON infrastructure requires very high initial investments, characterized by a long recovery time. However, without a PON infrastructure, manufacturers will not offer PON technology, telecom operators will not be capable of delivering new types of services, the supply of new PON technologies will not drive bandwidth demand, and without sufficient demand, the infrastructure will not be profitable.

The type of implemented PON architecture can limit a new PON technology implementation. Several characteristics have to be taken into account regarding infrastructures, namely if the operator owns the fiber or if it is rented fiber, type of CO, location, and capacity, splitting ratio and consequently optical power budget, the existence of flexible fiber points between OLT port and first splitter.

Regarding CO, the OLT can be located on a building, with temperature-controlled and no space limitation, or they can be located in a street cabinet or a pole. Depending on the location, several uncertainties may arise, such as: if the OLT shelf has the physical capacity to accommodate new boards; if their current backplane and data capabilities support the new boards for new PON technology; if the PON technology has the same density as currently installed technology, i.e., 1:1 capacity; if it is necessary to install coexistence elements so that both technologies can coexist; and if the temperature support of the new PON technology is at least the same as for the legacy one. It has also to be taken into account the extra power consumption, CO fiber organization, and uplink capacity.

If the current OLT shelf is not capable of supporting new PON technologies, it is necessary to verify if current street cabinets or pole cabinets have the space and capacity to install the new shelf and the impacts on services disruptions.

Higher splitting ratios require higher transmitting and lower receiving optical power optics to accommodate the bigger PON power budgets. This, of course, imposes limitations on new PON technologies because they require higher speed optics to work on their physical limits. Also, an actual infrastructure with no optical power budget margin is always limited to coexist with a new PON technology since it will require changes on actual equipment to accommodate extra losses due to the integration and coexistence of future PON technologies.

The existence of a flexible fiber point between the OLT port and the first splitter is extremely important when considering a new PON technology. This flexible point allows the infrastructure to accommodate coexistence elements, filters for legacy PON, or even be used as the physical port for new OLT.

Infrastructure investments are guided by demand forecasts. Forecasts help delay investment in the first infrastructures since investors are afraid to end up with stranded assets very quickly.

Investing in new technology is guided by the investor's perception of future demand [6]. In the case of the PON market, this is new PON technology; it is still difficult to predict the date and pace of market penetration and to envisage what will be the level of long-term stabilization of demand.

The diffusion of technology is complex and often dominated by particular historical circumstances that affect the path of technological change [7].

On new PON technologies, which are trying to meet the need for higher bandwidth and reliability to support the services of tomorrow in the medium and long term, the uncertainty about demand is superior.

Political uncertainty

An uncertain evolution of the legal and regulatory framework also increases investment risks. This political uncertainty can come from inconsistency, lack of standards, or hesitant behavior by political authorities.

Changing of political directions further increases the uncertainty weighing on investment [3].

The transition to new PON technologies will not be possible without a stable framework and a clear vision from public authorities, a factor necessary to overcome the enormous technological and logistical challenges that still oppose this transition. For example, if the negotiation of a tax credit lasts too long, it will be in the firms' best interests to wait, as investment costs are likely to decrease in the future [8]. Public intervention is fundamental, allowing firms to appropriate the benefits of their innovations and encouraging them to innovate.

The European Commission aims to strengthen the competitiveness of Europe's economy with an explicit focus on digital communications technologies. In light of this, the European Commission's strategy puts forward multiple policy measures and financial instruments that encourage private and public investments in fast and ultra-fast networks [9].

The effects of regulation and deregulation have been the subject of debate and study by FTTH councils worldwide [10], [11]. Deregulation of wholesale broadband access where competition is sufficiently strong appears to have a positive effect on investment, as suggested by the example of Portugal. Regulatory policies that vigorously endorse infrastructure sharing and reuse could also benefit strongly to lower deployment costs. The policy focuses on empowering broadband via FTTH, disregarding the domestic bandwidth demand and solutions that use present broadband networks [12].

Standardization plays a major role in new PON technologies. The IEEE 802.3 Group, ITU-T SG15 question 2, and FSAN define all standards for PON technologies. However, the standardization process is long and complex. The IEEE 802.3 (Ethernet) standard development procedure is motivated by making the simplest and most cost-effective data link possible. ITU-T SG15 Q2 and FSAN ensure that everything needed is covered in an integrated standard system, which makes IEEE and ITU complementary [13].

The standardization process creates uncertainties regarding the evolution of new PON technologies:

"Because these standards are the product of consensus, it is often the case that the only way to achieve that nearly unanimous state is to choose the "all of the above" answer". For example, each operator has their own unique set of requirements. To get the support of as many operators as possible, the proposed system

must support the superset of requirements. On the technical side, typically multiple solutions to a certain technical issue are proposed by the system and device vendors. In most cases, one solution is considerably better than the others and it is selected. However, sometimes there are two solutions that are so equally matched that it is difficult to choose a winner.“ [13]

Investing in a new PON technology has a very high risk before standardization because a given technology may not reach a consensus in standardization and be discarded.

Competitive uncertainty

In a competitive framework, the effectiveness of the companies' action is conditional, and it depends on the strategies of the competitors.

Porter’s five forces model [14] is a basic tool for analyzing the market environment, the use of which is used to better understand the nature of competition. Understanding these forces as much as possible is fundamental for the success of companies and for the introduction of innovative projects. This analysis allows for prioritizing the most important elements in the sector and, from this, building a competitive advantage.

According to Porter [14], the chosen strategy must allow the company to isolate itself from competitive forces and, if possible, act on the environment in its favor. The five determinants of project performance are the negotiating power of clients, the threat of new entrants, competition from alternative products or services, supplier bargaining power, and competition between established companies, as seen in **Figure 2**.

- **Clients’ bargaining power** has a direct effect on quantities, prices, and conditions of sale and, therefore, on the profitability of the project. It especially depends on the balance between supply and demand. A single buyer facing a multitude of suppliers will have a

FIGURE 2 – Porter's five forces [14]

lot of power to determine the terms of the negotiation. The market power of demand also depends on other factors, such as the availability of substitute products. As an example, a broadband service provider with a bigger fiber to the home/building (FTTH/B) network has bargaining power with equipment PON manufactures as large as its ability to negotiate and may have access to equipment at a lower cost.

- **The risk of new entrants** is another important force. The entry of new competitors attracted by market profits reduces profitability. The degree of the risk depends on the characteristics of the sector and the barriers to entry (capital intensity and economies of scale, conversion costs, learning curve). As an example: *"Efforts to reverse unbundled access included the global standards for the PON that were to replace copper local loops, developed at ITU-T Study Group15. These simply omitted unbundled access because of the absence of new entrants, governments, and regulators to argue for its inclusion. The incumbent operators and their vendors wanted a closed version of PON, which improved the economics of network investment because it excluded service-based competitors"* [15].

- **Competition from alternative products** or services widens consumers' alternatives by making them more sensitive to price increases. High conversion costs and a low willingness of consumers to change make this competitive force less important, and vice versa. Competition amongst PON manufacturers is constrained, in terms of the numbers of rivals and the nature of the technologies, by the need for licenses and use of common standards, the obligations to interconnect and interoperate. By using common, usually global, technology platforms and business models, innovations are often easily replicated, and competition is limited. Differences in PON products are difficult for service providers to understand and offer a limited basis for competition.

- **The bargaining power of suppliers** to impose their conditions has an effect comparable to the bargaining power of customers. Here, the costs of switching suppliers are a key variable. They depend, in particular, on the existence of alternative suppliers. The high competition among supplying firms in the PON industry, the low product differentiation, the high number of substitutes, and the service providers' high level of product knowledge are factors that contribute to a reduction of suppliers' bargaining power in the PON broadband industry [16].

- Finally, **the degree of competition** in the sector is simultaneously the result of the other four market forces. Stronger competition generally means less profit. The sector's position regarding the life cycle of the product is another important factor for the strength of competition (growing or stagnating sector; phase of product innovation or process improvements; the number of companies high or reduced). *"The telecom industry is a very dynamic industry due to the vast changes in technology and the forces impacting the industry. Technological innovations, standardization, and regulatory mandates are some of the forces that can affect the competitive landscape in the telecom industry."* [17]

The five competitive forces are not disconnected but instead linked together. Thus, the environment favorable to the introduction of new technology is made up of a large number of buyers with little bargaining power, the absence of substitutes, the abundance of external sources of raw materials, intermediate goods, labor, and services, and finally weak competition between established companies (for example the innovator succeeds in having the monopoly of a profitable market whose profits reward the risks taken initially).

PON technologies cannot be assessed from the comparison with the ideal environment just described. First, technological substitution for new PON technologies must face the resistance of established technologies, particularly the GPON.

Second, a technological transition for a new PON technology has never occurred in the past, and therefore the behavior of demand remains very uncertain.

On the supply side, many companies are active in the production of new PON technologies around the world. However, a large-scale transition to a new PON technology poses the question of the availability of resources.

Uncertainty about available resources and supplier behavior

The development of radical innovations, such as new PON technologies, will likely come up against a lack of financial, human, and raw materials. These problems arise more prominently during the pre-commercial phase when it is difficult to provide all the resources necessary to carry out the project.

The financial needs necessary for the technological and infrastructure development of new PON technologies are enormous, and the companies involved will face difficulties in accessing external financing as the sector's profitability is still uncertain. This is more critical in the pre-commercial phase, during which significant expenses must be incurred immediately for income that will be generated in the future [18].

Sweeping innovations such as new PON technologies also require new human skills, which sometimes do not yet exist and therefore need to be trained. The lack of human resources is normally bigger in the case of disruptive technologies than in incremental innovations due to the critical character of skills associated with radical technical change.

Innovation can still be constrained by the limited availability of raw materials. Thus, for example, a new PON technology that requires the use of certain types of lasers with very specific performance can considerably increase production costs and raise questions about the competitive nature of large-scale production.

Innovation may also be constrained by the uncertain behavior of suppliers concerning the availability, quality, and cost of the supply [19]. In the context of new PON technologies, the choices of the players are interconnected: laser manufacturers, vendor equipment manufacturers, and suppliers to operators.

However, these uncertainties can be reduced by vertical integration [19]. This is how equipment manufacturers set up partnerships with lasers manufacturers producing new lasers for the development of new PON technologies.

Conclusions

This article reinforces what could be achieved by cooperation between the SP (customer) and the PON equipment manufacturers (suppliers) by giving the supplier access to the customer's real demand data. Customer–supplier relationships with close long-term cooperation simultaneously increase the value produced by the demand chain and decreases its overall cost. Good forecast models can be produced with the right data accessed, but the test of the validity of forecasting only really comes with the passage of time.

The PON investment must take into account the different market signs, such as the technological adoptions by the end-users, other telecom technologies, the mobile market, and the Wi-Fi market, as well as when and where.

Uncertainties are always surrounding the PON markets and the different solutions. This is a natural state for TELCOS and telecom operators, as the investment and expansion of their business are highly influenced by uncertainties of all kinds, namely, technological, infrastructural, political, and competitive/concurrency.

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DOI: https://10.57650/innovaction/2022.04

04 An e-health use case enabled by private 5G, AR and edge computing

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This article presents the technological scope for 5G exploitation in the e-health ecosystem. A concrete use case is here described, where the technological merging of private 5G, edge computing, and AR is exploited for an e-health application for remote cooperation between surgeons, where the different components have complementary roles. AR is an immersive technology that transfers digital data to augmented real-world surroundings and enhancing the user perception of reality. Applied to the healthcare ecosystem, AR, with 5G and edge computing, will escalate the current standard to high fidelity, effectively improving execution time, satisfaction, and confidence in post-graduation surgical metaverse education and training.

Keywords

E-health; Surgery; Augmented reality; Private 5G; Edge computing

Introduction

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

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

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

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

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

5G for verticals

5G differentiating characteristics

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

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

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

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

Non-public networks

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

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

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

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

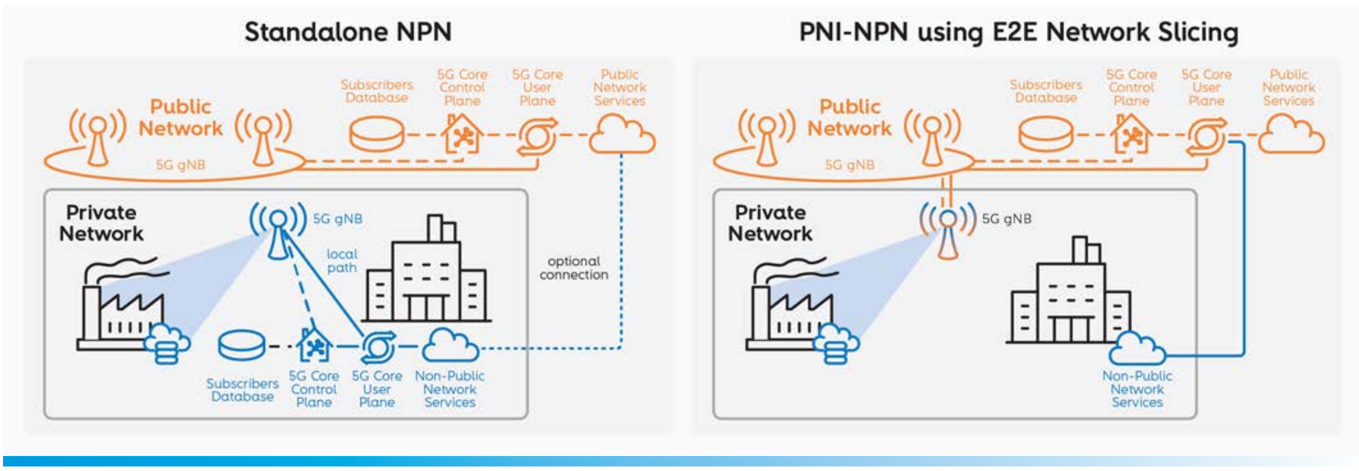

FIGURE 1 – NPN deployment flavors (5G-ACIA)

An intermediate configuration exploits the 5G control and data planes separation. Individual data planes for each industrial client are kept in their private domain, while the control plane is deployed at the service provider, maybe at the edge, being shared by different customers. However, while those scenarios are not mature enough, and standalone 5G PLMN are not widespread, the SNPN model is the one that is currently being mostly adopted.

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

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

5G and healthcare

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

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

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

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

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

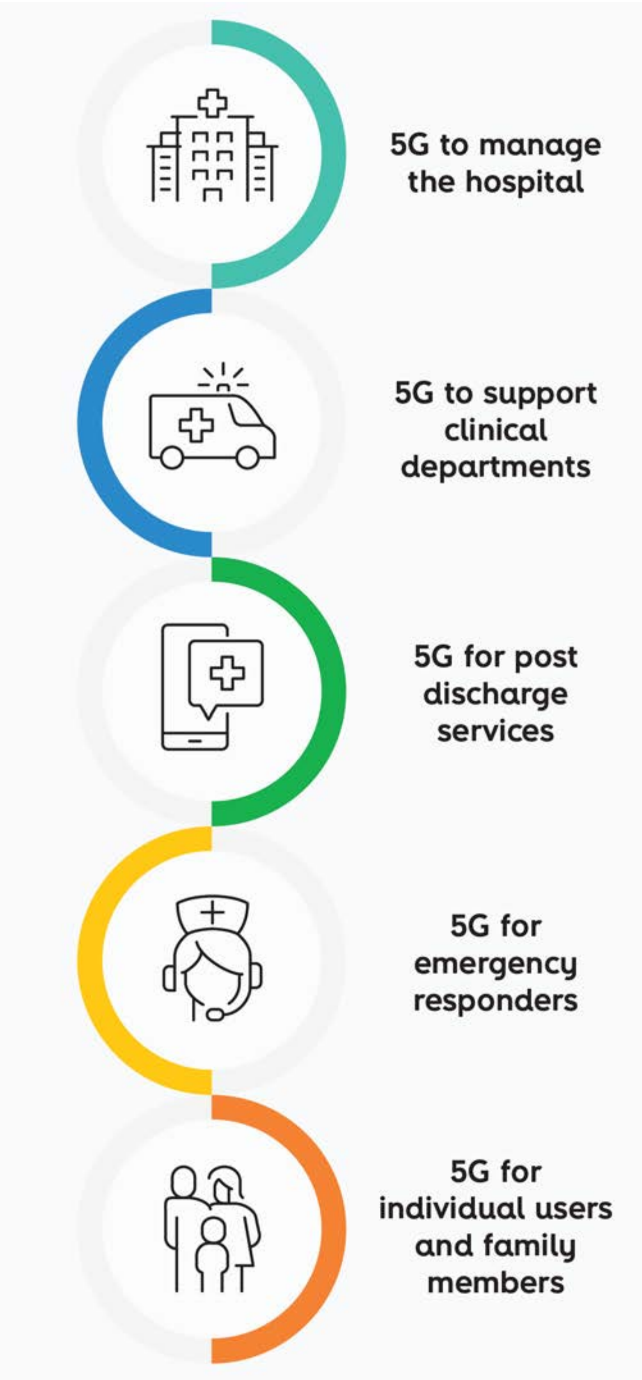

FIGURE 3 – 5G medical use cases [7]

The same document identifies opportunities and risks of 5G application in medicine (with identified risks not specific to the 5G technology), as listed in **Table 1** and **Table 2**.

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

TABLE 1 – Opportunities of 5G applications in medicine

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

TABLE 2 - Risks of 5G applications in medicine

STL Partners [8] also identifies ten 5G healthcare use cases and maps them into 5G characteristics (see **Table 3**).

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

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

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

AR enabled by 5G and edge computing

AR is an interactive experience in a real-world environment, where the seen objects are enhanced by visual and non-visual computer-generated information. The major outbreak to fully disseminate AR technology was the creation of handheld devices. In 2013 Google announced its open beta Google Glasses, and in 2015 Microsoft announced its augmented reality headset. The following year, AR entered the

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

TABLE 3 – 5G use cases vs. characteristics [8]

mainstream map with Pokémon Go (Nintendo gaming creation) tremendous success in 2016. And after the COVID-19 pandemic surge, AR remote presence and wireless communications became a daily need for millions of users.

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

Surgical metaverse

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

This breakthrough with immersive technologies opened a new era: that of the use of the so-called metaverse in post-graduate medical education. The surgical metaverse can be defined as the access to medical data via augmented, virtual, mixed, and extended reality through a headset within an ongoing surgical procedure and is already considered to be the next-generation mobile computing platform. It will transform the operating room of the future into an immersive surgical arena and a multimedia space, enabling surgeons to become 'super surgeons' by having real-time access to virtual objects during ongoing surgery.

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

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

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

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

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

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

Use case: AR and e-health

For the first time on May 5, 2022, a novel experiment in breast cancer surgery took place between the Champalimaud Foundation in Lisbon, and the University of Zaragoza, in Spain, during a live medical conference [18], as shown in **Figure 4**.

FIGURE 4 – Audience in the room, following the demo

Rogelio Andrés-Luna was in Zaragoza (more than 900 km from the operation site) with a laptop computer that was linked to Pedro Gouveia's HoloLens [19] using dedicated software developed by remAID [20].

That 'remote surgeon' in Zaragoza, despite the considerable physical distance between the two doctors, was able to supervise the 'performing surgeon' in his delicate task in the operating room as if he was right next to him, sharing the same visual field.

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

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

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

For the demo, Altice Labs made available a 5G private network 'in-a-box' composed of servers, switches, a router, and a 5G indoor radio unit (as represented in **Figure 6**).

This network provided indirect connectivity (USB tethering via 5G smartphone) to the doctor's Microsoft HoloLens 2 as these AR glasses do not have native 5G support.

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

FIGURE 6 – 5G 'in-a-box' used kit

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

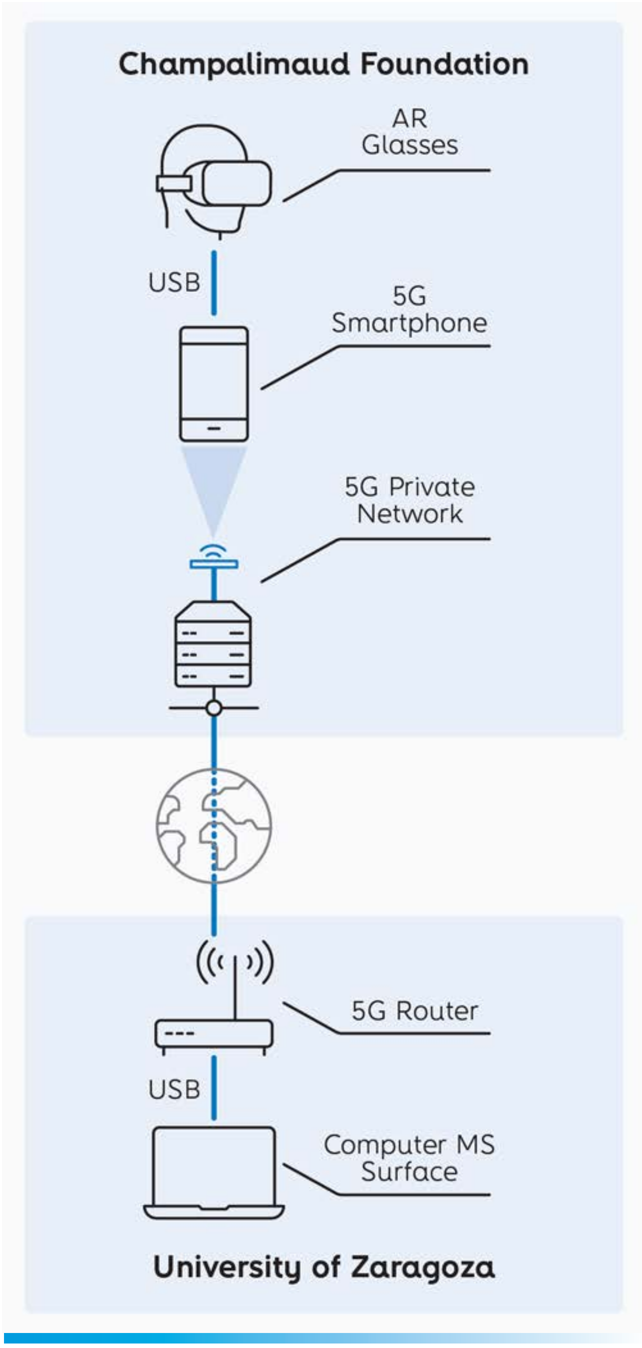

FIGURE 7 – End-to-end diagram used to setup the demo

Altice Labs' 5G RAN in the context of NPN

Altice Labs' 5G solution for SNPN incorporates all the components required to deploy an end-to-end 5G network, supporting the creation of non-public networks for different verticals, boosted by industry 4.0 and digital transformation movements. It includes the radio access network (RAN) radio units (RU), the RAN software components (centralized unit – CU and distributed unit – DU), the 5G Core, the required element management system (EMS), and hardware servers. It is also capable of integrating non-5G capable terminals via Altice Labs' developed gateways. This can be delivered in greenfield or brownfield environments. Altice Labs can also provide the networking solution, at all network sections, for instance, at the fronthaul, between RU and DU.

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

- Option 0: core network and CU
- Option 2: CU and DU
- Option 7.2x: RU and DU

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

Altice Labs have been experimenting and proving the integration of some 5G core solutions with

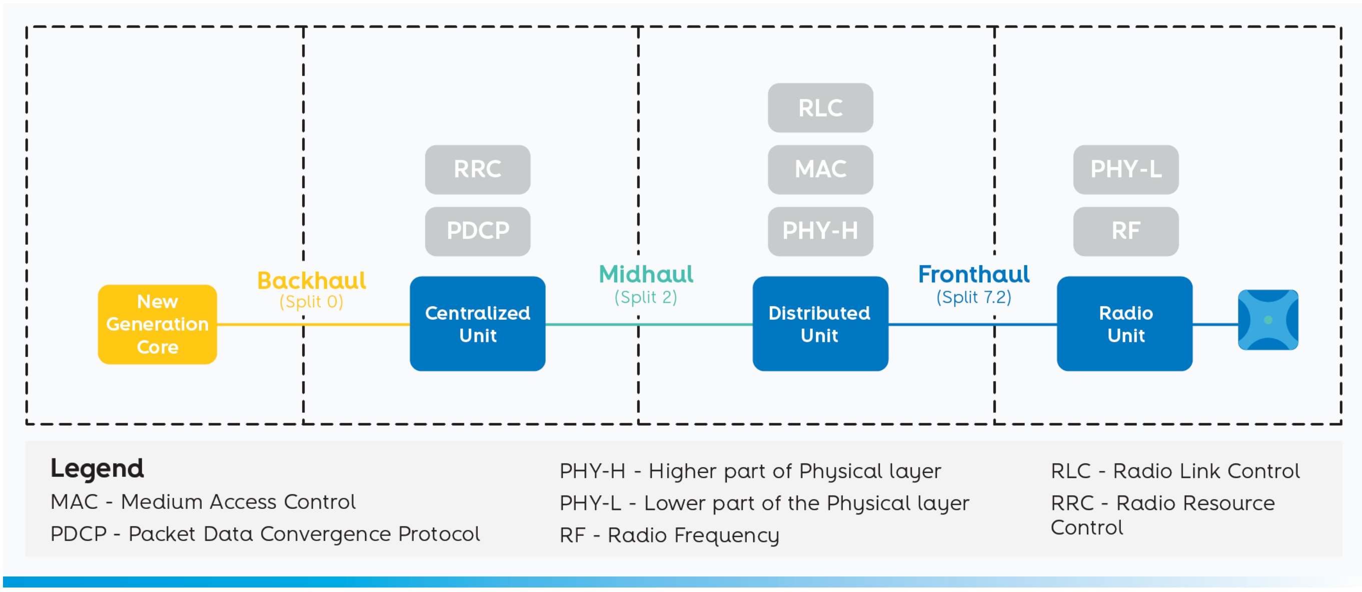

FIGURE 8 – Splitting points and functional components of Altice Labs' 5G solution

its RAN, from open source and vendors. Priority is being given to slicing and QoS capabilities, as well as to easy configuration, operation, and monitoring.

Conclusion remarks

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

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

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

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

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DOI: https://10.57650/innovaction/2022.05

05 Space communications and applications – a huge potential to unlock

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Satellite communications have recently entered a period of renewed enthusiasm motivated by technological advances and fueled by private investment and ventures.
The most promising applications are 5G non-terrestrial network integration, space communications, Earth and space observation, navigation, aeronautical and maritime tracking, extending broadband coverage to underserved areas (developing countries, aero/maritime, rural), and even sub-orbital tourism.
This momentum is propelled by novel approaches such as miniaturization, COTS, software-defined radio, reusability, automation, 3D printing, and big data analytics. Simultaneously, companies in the web sphere are investing in the ownership and management of terrestrial network stations to become major players in cloud processing close to the downstream market.

Keywords

Satellite; Space; Communications; 5G; NTN

Introduction

During the first two decades of the space age, each satellite was an art piece of the space craftsmen, where everything had its own design, all classified. From then on, satellite mass and complexity increased, targeting military, astronomy, navigation, earth observation, and telecommunication applications.

With advancements in technology, multiple satellites began to be built on single-model platforms called satellite buses. In the early 80s, microsatellites emerged and adopted a different design approach, with strict cost (shared rides) and schedule constraints, frequently combined with a single mission objective, focusing on available and existing technologies and using properly qualified commercial off-the-shelf (COTS) components.

As for the orbits' selection, it depends on what each satellite is designed to achieve.

Geostationary orbit

Geostationary orbit satellites (GEO) are placed in an orbit at 35 768km of altitude above the Earth's equator, following the Earth's rotation. This means that antennas on the ground can be permanently pointed at a given position in the sky. Furthermore, this type of satellite covers a large footprint on Earth, so three satellites, equally spaced, can almost provide global coverage.

Low Earth orbit

Low Earth orbit (LEO) satellites are placed below 2000km altitude. As a reference, most commercial airliners fly below 14km. LEO orbits are often tilted, which provides multiple orbital planes. These orbits are constantly and carefully monitored as there are collision risks due to the high volume of satellites in these orbits. The proximity to Earth makes this orbit useful for Earth observation (EO) and telecommunications services (round trip delay shorter than for GEO and higher bandwidths). A typical LEO satellite circles the Earth on a Sun-synchronous polar orbital, meaning they travel at around 7.8km/s, taking 90 minutes to circle the Earth. This high velocity creates other issues for telecommunication services, namely the Doppler effect. In most cases, LEO satellites operate as part of a large constellation that creates a 'net' around the Earth.

Multiple companies, such as SpaceX, Amazon, OneWeb, and Telesat, have already announced large LEO plans, aiming to deliver high-throughput broadband services with low latency as well as internet of things (IoT) services and machine-to-machine (M2M) communications.

SpaceX started launching Starlink satellites in 2019. As of 2022, Starlink consists of over 3000 mass-produced small satellites in LEO, which communicate with designated ground transceivers providing satellite internet access coverage to 40 countries [1]. Currently, the number of subscribers has ascended to nearly 500 000. It also aims for global mobile phone service after 2023. In total, about 12 000 satellites are planned to be deployed, with a possible later extension to 42 000 [2].

Likewise, the OneWeb satellite constellation is a planned initial 648 satellite internet constellation completed in 2022. By the end of 2023, it aims to provide global broadband internet services [3].

On the other side, Amazon has signed launch contracts for 91 launches over the next decade to build out the Kuiper constellation, now planned to contain 3276 satellites [4].

As for Telesat, it filed plans for expanding the satellite count to its LEO constellation to over 1600 satellites [5].

The CubeSat standard

The CubeSat [6] standard was conceived in 1999 by professors Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University, and consists of multiple form factor elements of 10x10x10cm cubes (known as 1U and shown in **Figure 1**). The initial idea of this concept was to allow graduate students to design, implement, test, and operate a satellite using COTS components for electronics, structure, and avionics. The simplicity of the standard, its lower cost and interfaces, and the fact that so many students were involved in CubeSat projects led it to become the de facto standard [8].

As of November 2022, 77 countries have launched nanosatellites or CubeSats. The total number of nanosatellites launched is 2067. Most of them (1897) are CubeSats, and 1192 are currently operational [9].

Due to its lower cost, CubeSat-based missions can now reduce the revisit time, which offers new science opportunities such as multipoint high temporal resolution of Earth processes, mitigation of data gaps, and continuous monitoring [8].

Concurrently, the development of EO technologies (high-resolution multispectral imagery, light detection and ranging – LIDAR, radio detection and ranging – RADAR, synthetic aperture radars – SAR, and global navigation satellite system – radio occultation – GNSS-RO) made possible that several companies developed commercial CubeSat constellations to exploit this data [8].

FIGURE 1 – 1U cubesat structure without outer skin [7]

CubeSat limitations

However, there are limitations, mostly due to the smaller dimensions of the CubeSat, which makes it difficult to fit the large aperture and focal lengths required to collect faint signals and achieve large angular resolution. Furthermore, typical CubeSat missions have short lifetimes once in orbit, up to 4-5 years in some cases. Many technologies still need to be developed specifically for CubeSats to increase communications performance and resiliency, thermal stability, radiation hardness, and calibration accuracy [8].

Satellite telecommunications market

Satellite telecommunications companies provide customers with wireless signal reception and transmission services using orbital satellites as a transponder. Typical services are broadband connectivity in remote areas, IoT, direct-to-home (DTH) television, and geolocation. In general, the ground terminals communicate directly with the satellite over radio frequency (RF). The satellite receives, processes, and relays the data to other ground stations, as shown in **Figure 2**. Typically, the uplink frequency is higher than the downlink.

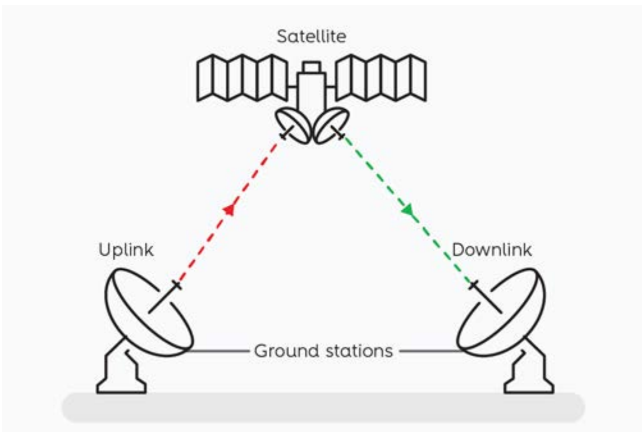

FIGURE 2 – Satellite communications

Limitations

As mentioned, the round-trip delay of satellite communication is a key impairment, especially for GEO satellites. This issue is minimized with LEO satellites when flying in formation (constellation), which significantly reduces the signal delay.

On the other hand, optical inter-satellite communications use high-power lasers instead of RF links. It has been gaining traction due to the need for larger capacity and higher bandwidth and the fact that they do not need frequency coordination and regulation. Furthermore, it requires high-precision pointing techniques.

5G and non-terrestrial networks

By the end of 2022, more than 1 billion people were expected to live in areas with 5G coverage [10].

The key benefits of 5G technologies are high bandwidth, low latency, and service continuity. The industry is now working on seamlessly merging the developments on 5G with satellite communications as a means to explore further other business opportunities, from the logistics of unmanned cargo transportation to IoT everywhere. The main advantage of bringing satellites into the equation is that they provide network coverage in areas where it is not possible to build cellular towers or it is too expensive to do so, and they add the safety factor in case there is an outage of the ground service.

Non-terrestrial networks (NTN) have been part of a gradual shift of research focus and the industrial push towards 5G Advanced, leading to sixth-generation (6G) systems [11].

3GPP is the primary international body responsible for defining the technical specifications for mobile wireless networks. The work on NTN started in 3GPP in 2017 and focused on deployment scenarios and channel models [12].

3GPP has identified three main use cases for NTN:

Service continuity: the combination of terrestrial and non-terrestrial networks provides service continuity. Some examples are commercial airliners and vessels.

Service ubiquity: to address unserved or under-served geographical areas where terrestrial networks may not be available. Some examples are IoT for agriculture, asset tracking, metering, and emergency networks.

Service scalability: Leverage the large coverage area of satellites and use multicasting or broadcasting. An example would be the distribution of TV content (i.e., ultra high-definition TV). The customer experience, above price and brand, is the second most important buying factor.

Currently, the 3GPP radio access network (RAN) is specifying feature enhancements [13] [14] such as:

- New approaches to address issues related to satellites' long propagation delays, large Doppler effects, and moving cells. These involve enhancements on timing relationships, hybrid automatic repeat requests (HARQ), and uplink synchronization;
- Some protocol stack functionality is also being enhanced in the user plane. Normative changes involve aspects such as the adjustment of allowed values for timers to take into consideration larger latency, improvements on random access channel (RACH) access procedure, and enhancement of uplink scheduling. In the control plane, mobility procedures are enhanced to better support satellite use cases;

- Architectural enhancements such as feed link switchover, as well as cell-related aspects, such as automatic neighbor relation (ANR), user equipment (UE) registration, and paging, are being developed;
- UE radio resource management (RRM) and RF requirements;
- Mobility management with large coverage areas and with moving coverage areas;
- QoS with satellite access and with satellite backhaul;
- RAN mobility with non-geostationary (NGSO) regenerative-based satellite access;
- Regulatory services with super-national satellite ground station.

3GPP is also working on enabling the operation of the IoT NTN. This work is based on the existing 3GPP features of narrowband IoT (NB-IoT) and enhanced machine type communication (eMTC), introduced in Release-13, over satellite communications. It assumes that the bands utilized are in the sub-6GHz frequency range, with both LEO or GEO satellite orbits, assuming a transparent payload [10].

NTN use cases evaluation

Detailed non-terrestrial 5G use cases for enhanced mobile broadband (eMBB) are listed below:

- **Multi connectivity:** Users in underserved areas are connected to the 5G network via short latency links (regular cell towers) for data-sensitive traffic and via long latency links (satellite) for less delay-sensitive traffic
- **Fixed cell connectivity:** Users in isolated areas or industry premises (mining, offshore platforms) can access 5G services and get high data rates via satellite.
- **Mobile cell connectivity:** Passengers on board vessels or airliners (moving platforms) can access 5G services and get high data rates via satellite.
- **Network resiliency:** Some critical network links require high availability, which can be achieved through the aggregation of multiple network connections in parallel. The intent is to prevent a complete network connection outage. The satellite link can provide the backup link.
- **Trunking:** For disaster relief, a network operator may want to restore 5G service in an isolated area by providing broadband connectivity between the public network and a mobile network anchor point or between the anchor point of two mobile networks.
- **Edge network delivery:** In order to offload the mobile network infrastructure, media and entertainment content such as live broadcasts, multicast streams, and group communications are transmitted in multicast to RAN equipment at the network edge, where it may be stored in a local cache or further distributed to the user equipment.
- **Direct to node broadcast:** TV or multimedia service is delivered to home premises or

on board a moving platform where other technologies are unavailable.

- **Direct to mobile broadcasting:** Public safety authorities want to be able to instantaneously alert the public (or specific subsets of it) of catastrophic events and provide guidance to them during disaster relief while the terrestrial network may be down.
- **Automotive:** Automotive industry players want to provide firmware/software over-the-air services (FOTA/SOTA) to their customers wherever they are. This includes information updates such as map information, points of interest, real-time traffic, weather and early warning broadcasts (for instance, car accidents), parking availability, infotainment, etc. Also, the media and entertainment industry will be able to provide entertainment services in cars, buses, trucks, etc.

As for massive machine-type communications (mMTC), it is expected that this technology will provide connectivity to multiple IoT sensors and actuators scattered over or moving around a wide area and reporting to and controlled by a central server. The following telematic applications are envisioned:

- Automotive and road transport: high-density platooning, HD map updates, traffic flow optimization, vehicle software updates, automotive diagnostics reporting, user-based insurance information (e.g., speed limit, driving behavior), safety status reporting (e.g., air-bag deployment reporting), advertising-based revenue, context awareness information, remote access function (e.g., remote door unlocking);
- Energy: critical surveillance of oil/gas infrastructures (e.g., pipelines);
- Transport: fleet management, asset tracking, remote road alerts;
- Agriculture: livestock management, farming.

Conclusions

Telecommunications have changed our lives dramatically for the better. Still, businesses and industries lag behind digital technologies in areas where the communication environment is poorly developed, and their problems remain unresolved. Non-terrestrial networks, delivering telecommunication connectivity from space, not just address these voids but also open many new business opportunities for regular operators and R&D companies that until now did not have access to this market, as it was reserved for the satellite communications. New constellations of satellite deployments and work at 3GPP have provided a possible pathway for closer integration of terrestrial and non-terrestrial networks, providing solutions for consumers and enterprises that integrate both types of networks.

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DOI: https://10.57650/innovaction/2022.06

06 How digital business & operations solutions are fostering a smarter life

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Through the last years, CSP embraced the cloud to achieve more flexibility and agility, but it's not enough. CSP must reevaluate their business models, review their technology systems architecture, and create portfolios to accommodate the changing needs of their customers, i.e., they need to change from TELCO to TECHCO.
This journey will directly impact the CSP culture and people, which need to re-adapt and reorganize to give focus and priority to co-creating, collaborating, reducing operational costs, and assuring QoE using intelligence in a data-driven model.

Keywords

TECHCO; CSP; Service assurance

Introduction

Communication service providers (CSP) are typically focused on developing and renewing their networks to support their service offers. They look forward to improving the market share with aggressive competitors and spending less on evolving and innovating their services and product portfolio. This approach requires a high capital expenditure that does not reflect revenue growth and even less market value [1], as would be desirable. On another side, CSP are faced with players, like over-the-top (OTT) and social network platforms, whose business depends on the connectivity and infrastructure provided by the CSP but without any investment commitment of them, generating a non-fair distribution of return on investment (ROI). Through the last years, they embraced the cloud to achieve more flexibility and agility, but the results until now tell us that they are not enough. This challenges CSP to reevaluate their business models, review their technology systems architecture, and create portfolios to accommodate the changing needs of their customers.

Changing CSP from TELCO to TECHCO is another way of saying 'TELCOS need to transform' and is also a new way of working.

TELCOS also need to improve and innovate in several strategic lines, like working in new ecosystems through partnerships that together can deliver new outcomes to customers, making data a valuable asset, adopting new 'digital' technologies, namely the cloud migration, bringing intelligence and agility to the operational processes through the use of artificial intelligence (AI) /machine learning (ML) and standard API.

Digital business

While facing the pandemic, most human interactions shifted to online. Operators reacted by adopting fast response processes and providing ways to make possible a rapid shift in behaviors with an absolute focus on customer support and its new connectivity needs. Additionally, they supported an entire ecosystem of suppliers and distributors that relied on digital to complete their transactions, ensuring the consumer's basic needs and well-being.

A Mckinsey report [2] points out some interesting numbers about major shifts in digital customers:

The adoption of digitally enabled products has been accelerating for about seven years.

More than 30% of buyers already use digital and self-serve channels for several stages of the buying journey.

The customer experience, above price and brand, is the second most important buying factor.

Accordingly to McKinsey [3], the consumer foundations for brand loyalty and engagement and product/service purchase are almost entirely emotionally based. This 2022 research from brand keys shows a decision-making ratio of 80% emotional against 20% rational, evidencing the emotional connections as the new age of customer experience key. It increases the importance of cognitive digital communications, mainly with the digital voice conversation as an essential tool looking forward to a more empathic interaction and consequent customer engagement, supported by AI and ML mechanisms.

In a general way, digital business needs to implement several technological aspects to operate and grow. These aspects are presented in **Figure 1**.

Cloud Adoption will provide the flexibility and agility necessary to fast launch and scale new service branches. It requires specific skills mainly due to complexity, cybersecurity, and data privacy.

Internet of Things (IoT) is key to the development of smart products. 5G will become a catalyst to reach their goals even faster through this technology's revolutionary user navigation experience, such as higher multi-gigabits-per-second speeds, ultra-low latency, and greater reliability, and also taking advantage of the advent of 5G network slicing with its capacity to create private networks with personalized characteristics according to the business case needs.

Process Automation, through task management systems, to automate workflows, enhancing productivity and achieving lower operational costs.

Artificial Intelligence aims to help the organization anticipate customer needs, forecast operational problems, support the decision process, and improve customer experience, for example, through voice analytics, providing cognitive voice interactions supported by natural language processing (NLP), natural language understanding (NLU), and ML algorithms.

Data Capture improves business intelligence by transforming the raw data into relevant information to help the business grow.

FIGURE 1 – Technological aspects to meet business needs

Digital co-creation

As the world becomes more connected, it rises an ecosystem of several players and sources that contributes to creating value. It is also possible to observe the growing importance of bringing business and technology perspectives together to get value from data. These aspects point to digital co-creation as a new way to deliver innovative services jointly with CSP partners and customers.

Metaverse has been showing potential opportunities to explore innovative co-creations, opening new routes to growth with an immersive virtual world. Ernest & Young [4] points out that TELCOS stand to benefit immensely by taking part in the Metaverse, not only as a Metaverse enabler but enhancing customer experience, monetizing investments through adjacent services, and increasing operational efficiency. However, for that, the CSP must expand beyond the traditional toward to find their place in the metaverse ecosystem and take advantage of the opportunity to position themselves as a co-creator of the Metaverse, jointly with technology giants and online game developers, and consequently leverage emerging technologies such as 5G, edge computing, analytics, and AI.

All customers are today seeking to make better use of their resources (like time, money, etc.). Also, the CSP and customer ecosystems are changing:

Home is now a central piece to work, study or even realize personal activities. Home tends to be as smart as possible.

Customers expect sales and service to be digital by default.

Technology is used to contribute to better health outcomes.

Mobility has been interrupted by reduced travel and population dispersion.

Connectivity becomes essential for economic recovery and the physical well-being of people.

More and more small and medium businesses (SMB) are going digital.

Over time, technological evolution and innovation have typically been driven to make people's lives easier and smarter. With 5G, IoT and virtualization are emerging in several areas with a focus on the customer, opening a range of opportunities to B2C, B2B, and B2B2x domains. Verticals of Industry 4.0 and private networks are a strong example of it, but also healthcare, autonomous vehicles, smart homes, retail, logistics and distribution, agriculture, public security, street lighting, media and entertainment, and much more, most of them fostering a smarter life.

CSP must do partnerships to give customers what they need and to be able to scale. In a time where 'almost everything' is distributed, not only in terms of cloud infrastructure but also in terms of ownership, CSP need to partner with vendors, hyperscalers, other ecosystem players, and with each other to co-create and get the coverage they need.

The challenges of a TECHCO

In what refers to TELCO operators' investments, and according to the TM Forum report [5], "*there is an argument that, as operators channel their resources into building fiber networks, there will inevitably be less funding – and less management focus – on new initiatives such as building new platform strategies. On the other hand, there is equally an argument that operators need to invest heavily in the simplification and automation of IT systems to reduce their costs in the medium-to-long term.*"

The revamping of IT systems, including business/operations management systems, is essential for any TELCO operator regardless of whether its investment focus is: network, technology, or lines of business.

According to the same report [5], the biggest changes that an operator needs to become a tech company are, by priority descending order:

- The automation of systems and processes, reducing complexity;
- Being more experimental in terms of investment in new capabilities;
- Change the relationship with vendors, bringing them into a partnership;
- Foster co-creation, pushing out the technology functions closer to the customers.

As for IT developments needed to achieve the automation stage, several main technical areas should be considered, like microservices software architectures, AI and ML technics, data analytics, standard API, and cloud-native systems, taking advantage of a DevOps methodology.

CSP need that their IT architecture becomes modular, reusable, cloud-native, AI-ready, and made of standardized components, according to TM Forum and Accenture [6]. With this approach, CSP will be able to implement new business models and revenue cycles, co-create through partnerships, keep operations at a needed lower cost, and even provide the flexibility demanded by the market.

The role of operations solutions

CSP are facing major changes in several domains, like network digitalization, IT paradigms, services provided, customer relationships, etc. Many of the opportunities identified for the next decade involve complex B2B2x business models, which require prioritization of the key issues of future business to be addressed, such as ecosystems, data-centricity, agility, and flexibility. This requires the evolution of the operations support solutions (OSS), adopting an architecture that enables end-to-end service orchestration and a data-driven service assurance applied to services and resources.

Several topics, like real-time operations, 5G network slicing, Open-RAN, distributed architecture, multi-cloud, services on-demand, and other goals, make end-to-end service orchestration an important platform that should automate the complex (and eventually manual and domain-specific) service provisioning. Its main characteristics must be multi-domain, catalog-driven, open API, multi-technology, and multi-vendor.

On the other hand, according to Ernest & Young [7], the improvement of customer experience is an ongoing goal for all CSP, and customer support is a critical part of that. The article also presents a survey showing that, on average, 43% of households have contacted broadband customer support in the last 12 months, and 23% are dissatisfied with the outcome. The survey also presents the drivers of dissatisfaction revolving around three themes: poor overall outcomes, time taken to address and resolve issues, and lack of information quality.

To address these themes, CSP should improve their assurance ability in various aspects such as the following, although not exhaustively listed in **Figure 2**.

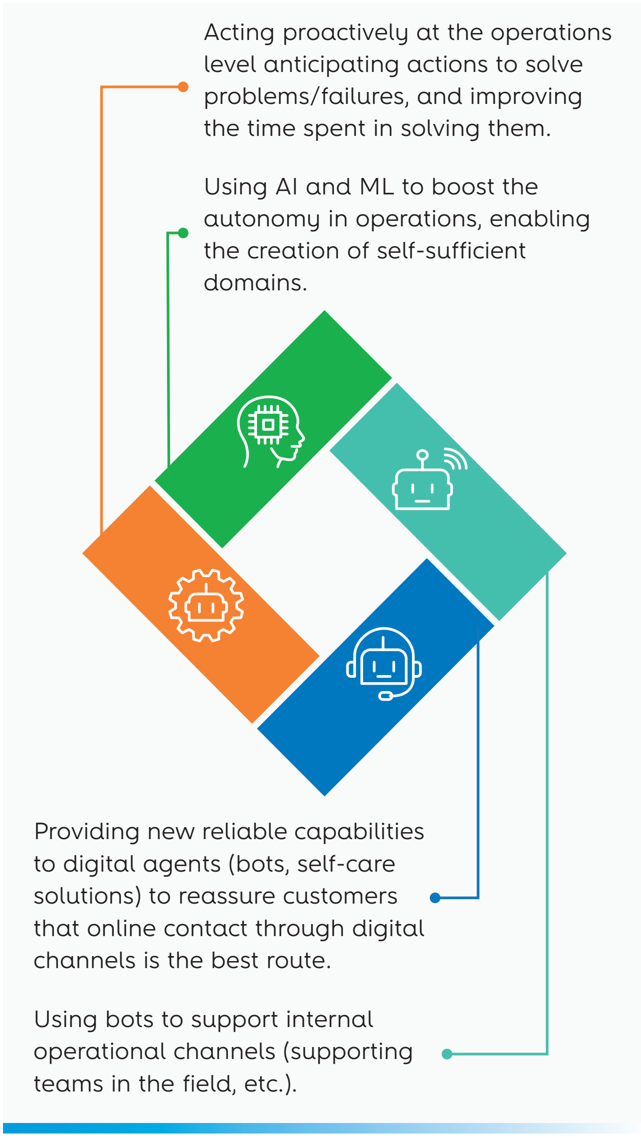


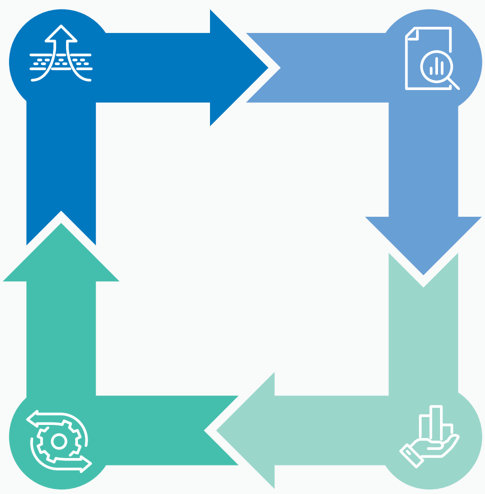
FIGURE 2 – CSP Assurance aspects

Introducing AI/ML algorithms and acting supported by a powerful orchestrator allows the development of the 'closed loops' leveraging the implementation of autonomous and cognitive operations that will enhance automation and efficiency in real-time scenarios, either in the proactive domain like problem detection, diagnosis, service/network degradation, network performance, and actuation in order to prevent the occurrence of faults and impact in the customer experience, or in the reactive domain enabling faster response, as automatic and autonomous as possible.

The closed-loop capability is supported by four main activities , shown in **Figure 3**.

Sensing: collecting service and network data from all layers (physical network elements, virtual infrastructure, SDN controllers, etc.) to feed assurance activities.

Analyzing: real or near real-time processing of network and service data, potentially enriched with other data sources (inventory, catalogs, etc.), helps to obtain the health status of the service.



Acting: end-to-end orchestration process, with service configuration and activation over physical or virtualized resources.

Decisioning: mechanisms determining and deciding actions for self-optimization, self-healing, and self-protection.

FIGURE 3 – Closed-loop activities

The value added by these activities depends on the network's ability to program itself as well as the implementation of AI/ML for data analysis and identification of insights that will enable the creation of new rules for actuation and decision-making. Technologies such as software-defined network (SDN) and network functions virtualization (NFV) will allow the increase of automation that is critical for digital transformation.

Figure 4 presents the operation's add-on block that integrates with Altice Labs' Assurance Solution (for collecting relevant data), Inventory Solution (storage and information owner), and Fulfillment Solution (for acting) to provide scenarios that will 'close the loop' and enable to achieve the autonomy.

This add-on block has two main components:

Design, needed to train the selected scenarios, using ML to analyze relevant collected data and generate new or enhanced policy decisions (like predictive failure alerts, diagnosis algorithms, and corrective activities) that will influence runtime automation decisions, price and brand, is the second most important buying factor.

Runtime, to collect, store, and process all data, enabling the execution of programmed workflows for the closed loop identified scenarios and supported by intelligent decision rules available from the design component.

An automated orchestration enables the creation of services across different network domains and, together with analytics AI, allows full closed-

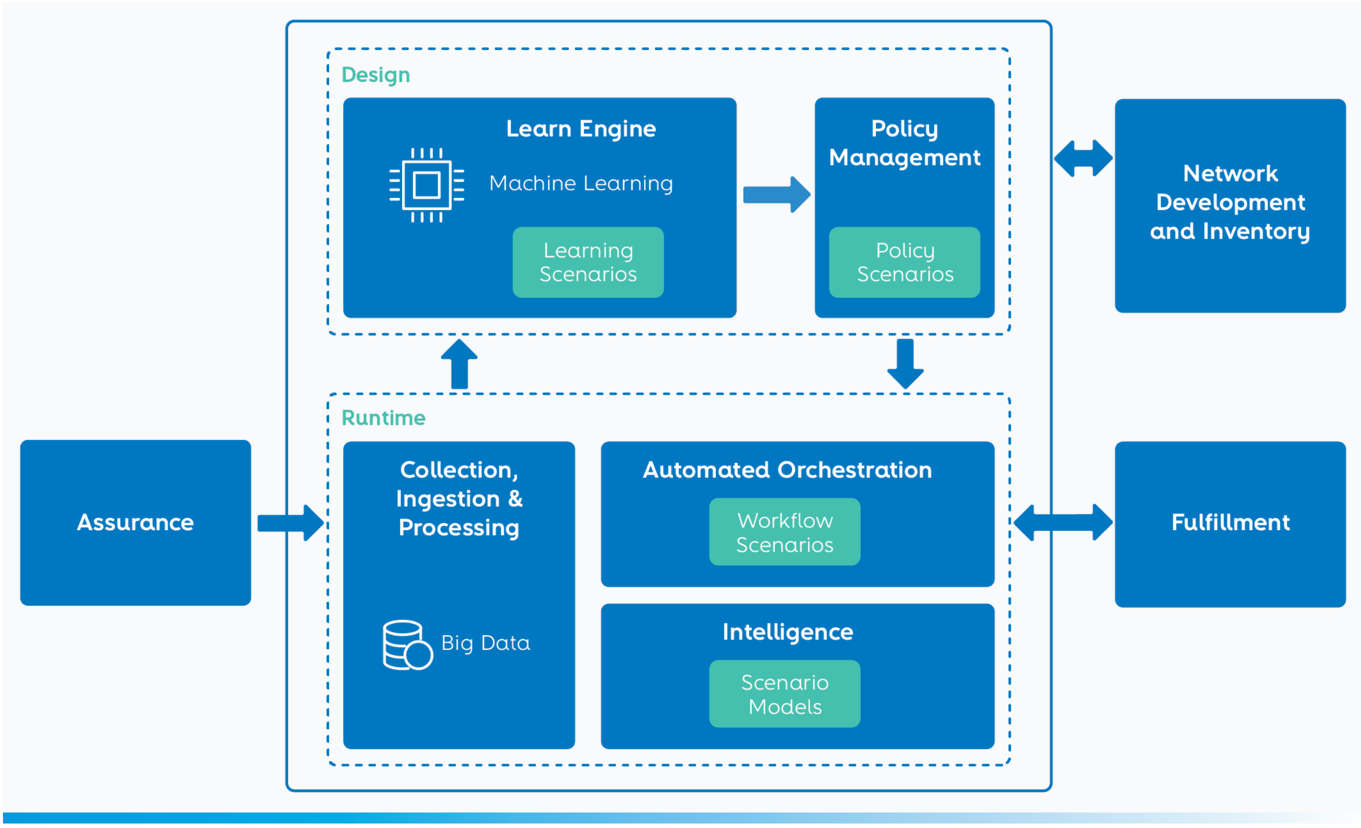


FIGURE 4 – The autonomous operations architecture

loop automation, reducing the operation cost of the network and services, minimizing human intervention, and implementing self-healing while proactively fixing any detected problems.

TELCO to TECHCO journey

CSP traditionally used to develop and renew their networks to support their service offers, invested in connectivity but with a flat revenue associated with their traditional voice and data services. They are now facing a digital world, leading CSP to develop a profitable ecosystem to achieve their future growth. This challenges CSP to be able to generate revenue through new business models, going beyond the ones they have practiced so far and leading them on a path of transformation that is expected to bring agility, automation, scalability, co-creation, and customer-centricity. This journey from TELCO to TECHCO requires the definition of a robust strategy transversal to several areas, as presented in **Figure 5** (on the next page).

Moving on an ecosystem of relationships with customers, vendors, service providers, hyperscalers, and other players, brings the opportunity to introduce and extract value from new technologies at the most varied levels, namely: 5G, cloud, systems architecture (microservices, API, etc.), bots, AI, NLP/NLU, among others, and also co-create scalable and innovative services and solutions.

Supporting these new digital services and their customers requires fast processes with a low dependency on human tasks, highlighting the need for intelligent, automatic, and autonomous operations.

All this journey will directly impact the CSP culture and people, which need to re-adapt and re-

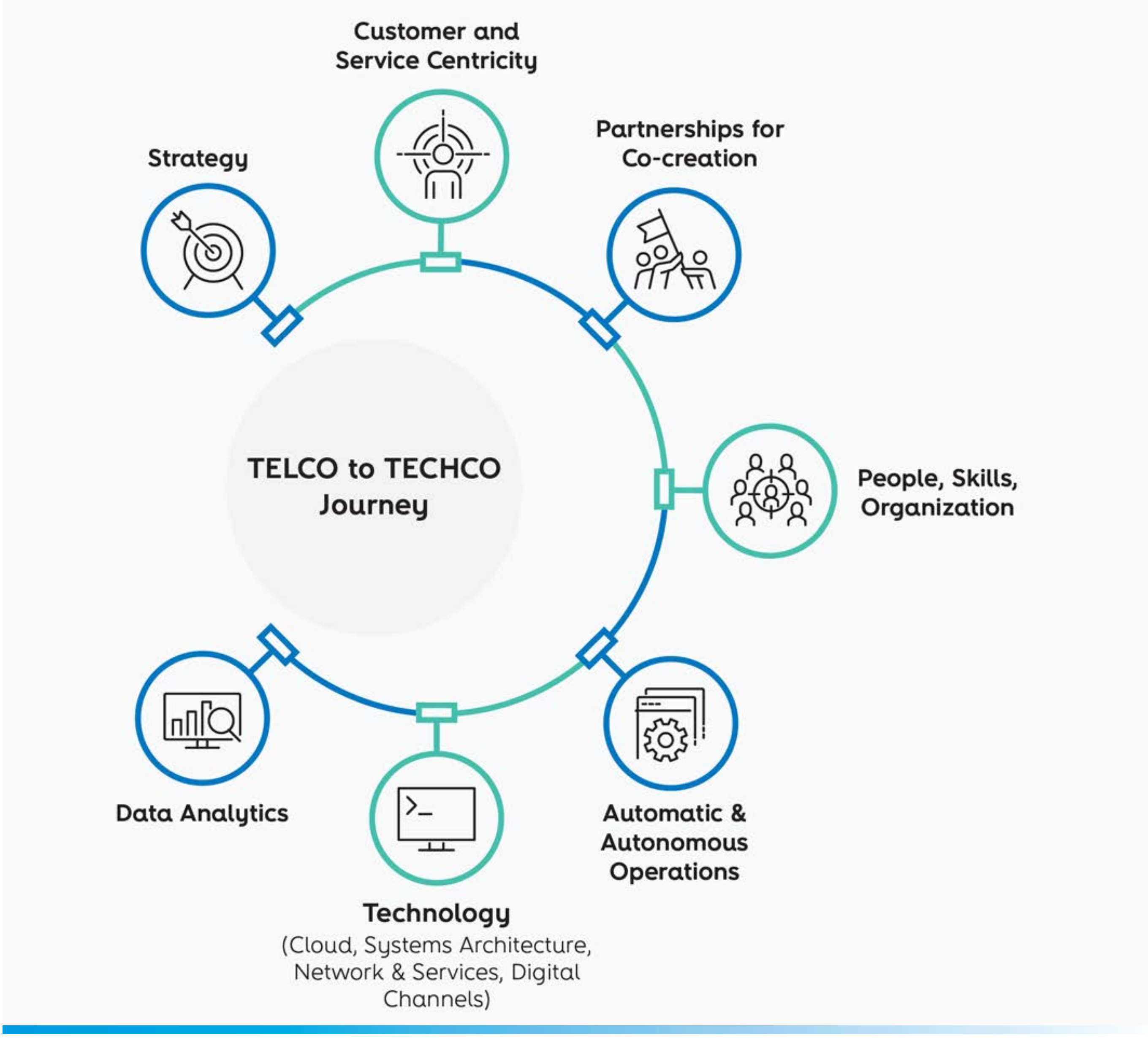


FIGURE 5 – The journey from TELCO to TECHCO

organize to give focus and priority to co-creating, collaborating, reducing operational costs, and assuring quality of experience (QoE) using intelligence in a data-driven model.

Conclusions

The innovation introduced by the TELCO to TECHCO journey, with particular emphasis on digital business and intelligent, and autonomous operations solutions, aims primarily to ensure the sustainability of the CSP and its revenues. It definitely fosters a smarter life for the end customer and those who work daily to ensure that the quality of the services delivered corresponds to the requirements and expectations of the customers.

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Coffee Shop
Department store
Restaurant
Bus

DOI: https://10.57650/innovaction/2022.07

07 AR over GIS to make field interventions more efficient

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Today, it is common to have mobile apps to access network inventory data from a smartphone or a tablet. These apps are based on traditional 2D technology with georeferenced inventory data presented over a map. With AR, the technician is able to see the inventory information on the screen on top of the real world captured by its device camera. This new way of interacting has an enormous potential to simplify the work, reducing the time technician needs to access the information he needs to perform his job.
Based on Altice Labs' Netwin AR app for FTTH proof-of-concept, this article highlights augmented reality technology disruption in improving the technicians' operational efficiency.

Keywords

AR; GIS; Network inventory; Netwin

Introduction

It is undeniable that the operational costs in TELCOS' field interventions are a major concern to the operators. Augmented reality (AR) is not a 'movie scene'. It is already present in our lives, and therefore the use of it by the operators among the inventory systems will positively impact the field operational efficiency and costs.

Augmented reality and GIS overview

AR corresponds to an interactive experience of a real-world environment where objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes through multiple sensory modalities, including visual, auditory, tactile, and olfactory [1]. AR can be defined as a system that incorporates three basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects [2]. The overlapping sensory information can be constructive (e.g., additive to the natural environment) or destructive (e.g., masking the natural environment). This experience is seamlessly integrated with the physical world so that it is experienced as an immersive aspect of the real environment [3]. The main value of augmented reality is how the components of the digital world blend with the perception of the real world, not as a mere data viewer but through the integration of sensations, which are felt as natural parts of an environment (see **Figure 1**).

The first functional AR systems that provided immersive AR experiences for users were invented in the 90s. Commercial AR experiments were first introduced in entertainment and gaming businesses. Later, AR applications spread across commercial sectors such as education, communications, medicine, and entertainment.

A geographic information system (GIS) is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to a map, integrating location data (where things are) with all kinds of descriptive information (what things are like there). Such a feature provides a foundation for mapping and analysis used in science in almost every industry. GIS helps users understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency as well as better management and decision-making [4].

Applying AR over GIS may be an effective solution to some problems of representing the GIS data over a 2D map.

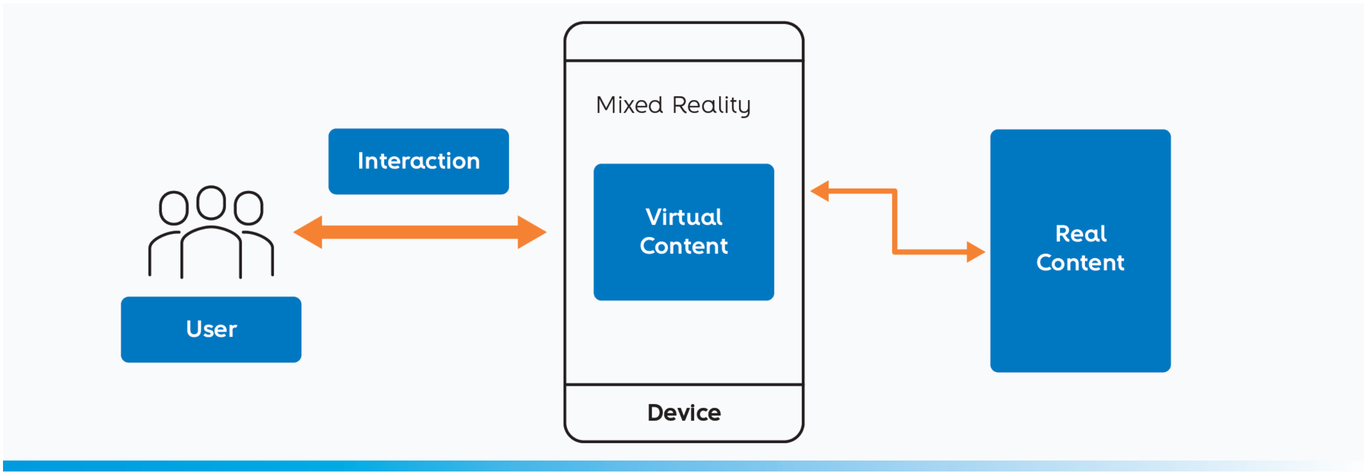

FIGURE 1 – How augmented reality works

Firstly, the representation of the data is much better linked to the real world, allowing the operator to see the GIS data in the world around him instead of connecting it to what he sees on a 2D map.

Secondly, the issues with precision and altitude may also be mitigated, as the data representation over AR is more faithful to the real objects than a 2D map representation. The accuracy advantage, however, is subject to the precision with which the AR content can be represented.

Developing mobile AR applications

While the first commercial uses of augmented reality occurred in the entertainment and video game industry, many other sectors such as education, data maintenance, and inventory management are also interested in taking full advantage of this approach [2].

The AR solutions in this domain will use the mobile equipment's location sensors, camera, or functionality. Thus, it makes sense to explore and consider the functions and the orders of precision of data they are capable of registering. This way, we can identify limitations in the proposed tools and, in the future, if such a possibility arises, identify the most effective equipment for the use of some proposed solution.

In the market, there are frameworks and tools that can be used to access AR features in mobile equipment. The ones that provide more flexibility and features are the multiplatform frameworks, which allow access to the native software development kit (SDK) features and add value on top of it.

One of the most relevant is the Unity framework [5]. Despite being most often associated with game development, this framework has a pertinent quantity of tools for 3D development that allows the implementation of AR applications. There are several SDK to develop over Unity, the most relevant of them being Vuforia and Wikitude [6].

One relevant aspect of using the Unity framework is that it allows to be incorporated into native applications of the equipment [7].

AR applied to network inventory

A network inventory product stores and provides information on network resources and their relationships. They include physical resources, like infrastructures (buildings, manholes, poles, strands, etc.), cables and types of equipment (racks, boards, ports, etc.), and logical resources (managed elements, VLAN, software, network topologies, VNF, etc.). Thanks to the smooth integration between network and IT, we have seen network inventory systems evolve to cover the IT world. As so, they are increasingly becoming more ‘resource inventory systems’. Some of them, like Altice Labs’ NOSSIS One Inventory (Netwin) [8], also include service inventory functionalities, providing a complete service-resource layered navigation, through GUI and API, according to worldwide standards and references, like TMForum.

The main goal of service and resource inventory systems is to support the operational processes of a service provider, namely the concept-to-market (C2M), the lead-to-cash (L2C), and the problem-to-resolution (P2R) processes. C2M deals with demand planning, network development (planning, construction, and inventory), and IT/service platform implementation to ensure service delivery readiness. The L2C process manages service fulfillment, including resource allocation, service activation, customer installation, and billing activities. It assures service delivery to the customer. P2R deals with network monitoring and resolution, preventive network maintenance, and customer problem resolution (service diagnostics and service repair).

Some activities of those processes require manual intervention on physical resources, most of them located on the outside plant, where some infrastructures and cables are underground. Network construction, customer installation, customer repair, and network outage resolution are examples of activities typically performed by technicians in the field that require access to the information available from inventory systems. Today, it is common to have mobile apps that are adaptations of the originating web applications to guarantee access to data from a smartphone or a tablet. Others are specific standalone mobile apps where inventory information is added to ensure the technician can perform his job. The majority are based on traditional 2D technology with georeferenced inventory data presented over a map, with some usability limitations and the subsequent impact on technician operational efficiency.

AR technology can be an alternative to the development of these mobile apps to present network inventory data. **Figure 2** shows the difference between using a 2D traditional approach and using AR to show infrastructures and underground cables.

With AR, the technician sees the inventory information on the screen on top of the real world captured by his device camera. When he walks through the street, the information on the screen changes in real time, aligned with his new locations. This new way of interacting has an enormous potential to simplify the work, reducing the time the technician needs to access the information he needs to perform his job.

Netwin FTTH use case

Fiber-to-the-home (FTTH) is a passive optical network (PON) technology used in the access network domain to let fiber into the home,

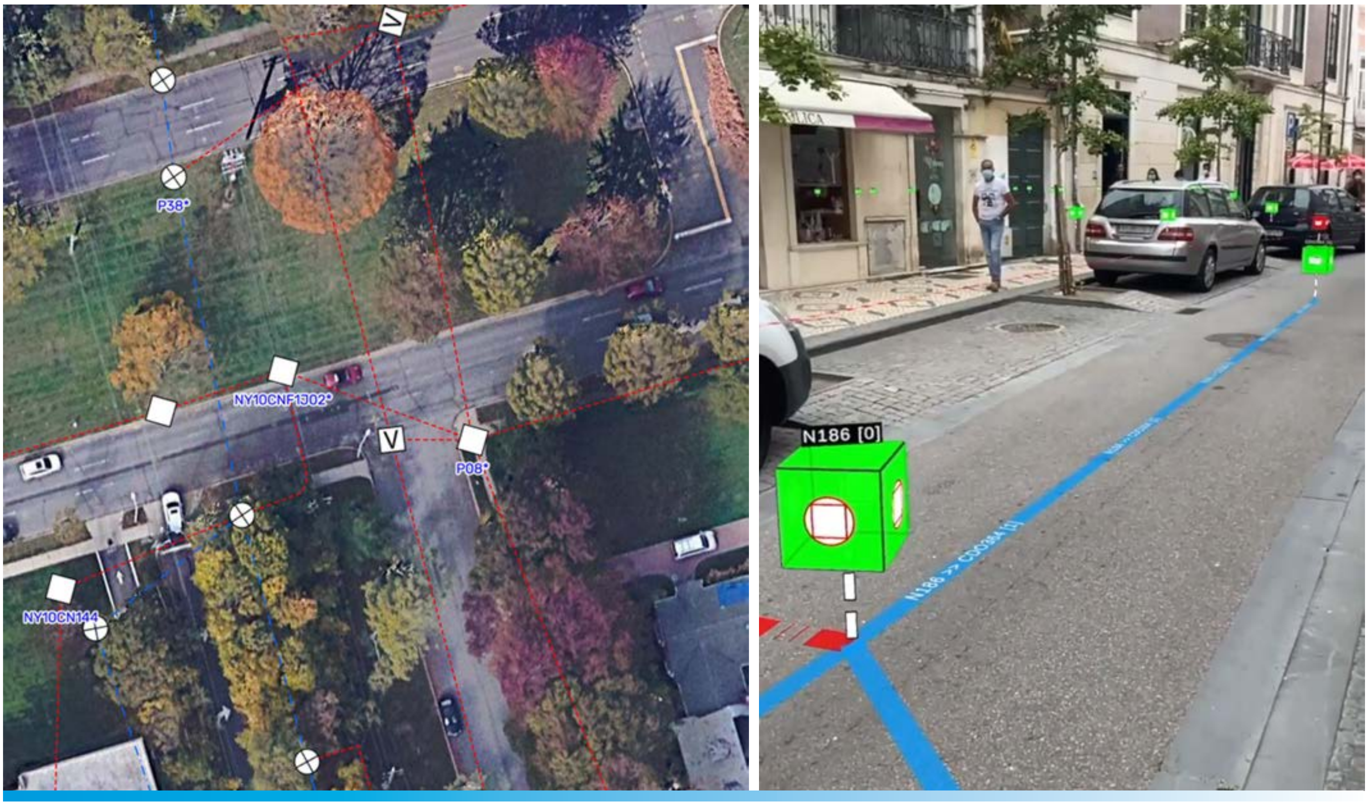

FIGURE 2 – 2D traditional approach vs. AR approach

providing high bandwidth at competitive prices for broadband residential and enterprise services.

This innovative technology caused a revolution in access networks introducing new challenges to operational processes and OSS systems. Advanced GIS inventory applications, like Netwin, are part of the solution and help fiber network operators to plan, develop and operate their networks efficiently.

Netwin provides intelligent network design, construction status, inventory accuracy with ready-for-service validation, and open API to support L2C and P2R processes.

FTTH operation processes include activities in the field such as customer installation and repair, and network outage handling, done by qualified technicians that need georeferenced information from service and resource inventory. Netwin provides a mobile AR app designed to provide the best usability and simplify technician tasks.

Using the AR capabilities of Netwin AR, the technician can see the Netwin information on top of the visible area so that he can have an overview of nearby network entities. **Figure 3** illustrates this situation, showing the FTTH physical infrastructure, underground cable ducts, manhole installation points, and optical distribution points (ODP) equipment in the real world.

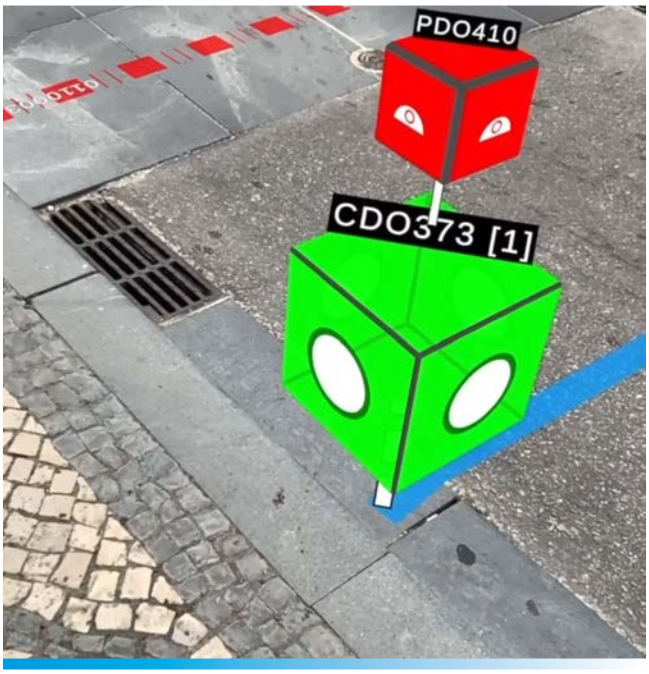

FIGURE 3 – Underground equipment

With a simple touch, the technician can see the characteristics of the elements (as shown in **Figure 4**), locations, strands, cables, equipment, and services. He can also perform data modifications and correct inventory errors.

FIGURE 4 – Detailed information on the visualized equipment

Another interesting functionality is the ability to search for elements. In this situation, Netwin AR will guide him to the destination. This feature is shown in **Figure 5**.

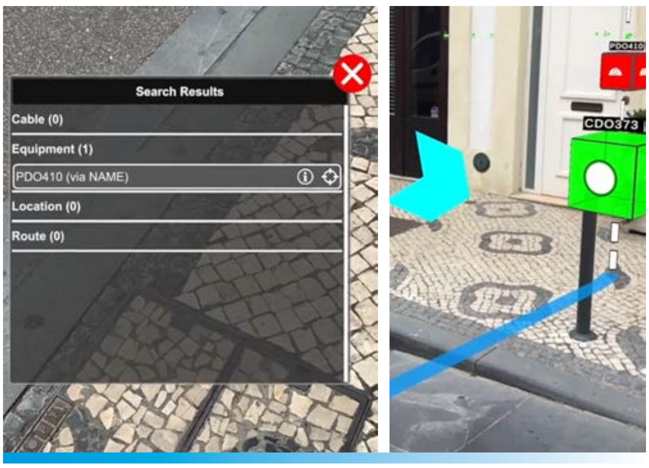

FIGURE 5 – Search elements

After a successful proof of concept, Netwin AR for FTTH is now becoming a product and will be available at the beginning of 2023 for android and IOS smartphones and tablets.

Conclusions

This article provides an overview of augmented reality technology and its application to view georeferenced network inventory information in mobile devices and help improve technicians' operational efficiency in the activities of L2C and P2R processes. The use of AR instead of traditional 2D technology is a disrupting innovation that opens an enormous potential for network inventory GIS-based applications, namely regarding usability and speed of accessing information.

A use case of AR applied to network inventory was presented based on Altice Labs' Netwin AR app for FTTH. The use of AR technology was described, and some examples were given. The app provides FTTH Netwin information in the field, on top of real-world information, using smartphones or tablets. This innovative approach can simplify the technicians' work: they will have a more natural and rapid way of seeing the information, which improves their operational efficiency. For the above reasons, we believe that Netwin AR app will go far from a proof of concept and become a successful product in the 1Q23.

Acknowledgments

The authors would like to acknowledge the collaboration of Allbesmart (http://www.allbesmart.pt/) in the writing of this article.

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DOI: https://10.57650/innovaction/2022.08

08 NOC automation, another step towards autonomous operation

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The paradigm of telecommunications networks has changed radically, and the survival of CSP depends on their ability to change and adapt.
Services will tend to be more numerous but also more specialized and personalized. Thus, management, monitoring, and automatic action become crucial.

Keywords

Autonomous operation; Automation OSS; Assurance; NOC; Network Operations Center

Introduction

In the last 15 years, the type of consumption of telecom operator customers has changed substantially. The use of the fixed telephone has become an accessory or even non-existent, the mobile phone is no longer exclusively used to make calls or send SMS, and the offer of television channels has become insufficient. We live in an era of massive service consumption based on the immediate availability of information, intended to be within everyone's reach at any time and place.

Content growth and the evolution of the network are bound together. In an endless race, the evolution of the network is stimulated by the various players in the telecommunications market. They continuously introduce improvements to their network in order to enhance their services and increase their offer. 5G is an example of this. The palette of opportunities to leverage new ways to monetize the network is vast. Still, the price to pay for each customer's differentiated and tailored offer requires new ways to manage, monitor, and act on the network. *"5G in its standalone incarnation brings the promise of new revenue streams for communications service providers (CSP) and more differentiated services that better meet customers' specific needs, but it will also add complexity"* [1].

The massification of services consumption, which depends on their base on telecommunications services, mobile or fixed, poses operators with a considerably complex network and process management challenge. The quality of service, perceived by the customers in a continuous way, and the resolution time of network failures become increasingly critical based on the dependence that we all have on the network. But we must also consider that the number of terminals that each of us uses simultaneously increases the use of the network.

It is also important to note that the emergence of new technologies promotes network evolution. Yet, the management of legacy networks is sometimes prolonged due to various restrictions, which imply that engineers must operate multiple types of networks simultaneously.

That said, it is imperative that CSP find ways to automate network management processes, such as identifying problematic situations and their resolution whenever possible in an autonomous way or with minimum human intervention. *"Manual and static programmatic and rules-based automation must give way to more model- and knowledge-driven approaches"* [1]. Only in this way will it be possible to increase the offer and continue to leverage network usage.

NOC: history and evolution

A network operations center (NOC) is one of the locations from which network monitoring, control, and management are exercised over a network.

The earliest NOC started during the 1960s and were aimed at real-time monitoring of telephone switches and routing information. Back in those days, NOC engineers had a full understanding of the network they were monitoring, and everything was done manually. There were few problems and enough human resources to deal with them in real-time (even the notion of real-time has changed over the years – back then, a few hours or even days of delay was considered real-time). Network changes were very rare and, when they indeed happened, were carefully planned, and as so, NOC engineers would get specialized training in advance.

Sixty years have passed since that first NOC, and today, the reality is quite different. NOC have been struggling for the past years with the exponential increase of networks and services. On the other hand, the pressure to reduce costs has never been so high, causing an unbalanced relationship between networks, services, and human resources. New technologies appear overnight, and the network is continuously changing, getting bigger and more complex. Each NOC engineer must deal with multiple technologies, and solving a problem usually involves several people due to network complexity. Every day, there are crises with instant visibility to major stakeholders and continuous pressure to reduce mean time to know (MTK) and mean time to repair (MTR).

Robotic process automation (RPA) has been implemented by most CSP to automate repetitive, low-value human tasks. A truly autonomous operation goes much further and requires more than just developing open digital architectures, using standard API, and adopting analytics, artificial intelligence, and machine learning technologies.

To measure NOC maturity, the TM Forum Autonomous Networks project has developed a six-level maturity model that CSP can use to measure their progress (shown in **Figure 1**) [2]. Each level has a set of characteristics that describe the developmental stage of the CSP from fully manual to fully autonomous operation. The model ranges from level 0 to level 5, with the degree of operational autonomy increasing at each level.

- **Level 0 – manual operation & maintenance:** the first stage of the journey – everything is manually done by humans without any automation. Despite being the 'old way' of working, 12% of operations admit they are still in this stage.
- **Level 1 - assisted operation & maintenance:** certain operation rules are pre-configured by humans to perform repetitive and isolated tasks within the system. Almost 40% of the companies recognized are at this level of maturity.
- **Level 2 - partial autonomous operations:** at this level, the system enables closed-loop operations and maintenance in some instances based on AI modeling. The rules and policies must be manually managed by humans. About 30% of the inquired companies are in this stage.
- **Level 3 - conditional autonomous operations:** advanced AI-based analysis techniques are integrated to identify the root causes compromising the network and service performance parameters. In this phase, the decisions and actions to close the loop are still manually implemented. Only 8% of the inquired operations are in this stage.
- **Level 4 - high autonomous operations:** building on the capabilities of the previous levels, the system is enhanced with AI-based decision-making procedures, incorporating policy-driven network management. This is the level with the lowest percentage of companies: 2%.

FIGURE 1 – NOC maturity levels of TM Forum Autonomous Networks [2]

- **Level 5 - full autonomous operations:** this level is the final step in the evolutionary path of autonomous operations. The system can implement a full autonomous lifecycle (infer, analyze, decide, and act) across multiple services and domains without the need for human intervention. Almost 8% of the operations have reached this level!

By 2025, according to the same survey, 70% of the NOC believe they will be at level 3 or greater [2], as shown in **Figure 2**.

"Highly automated network technologies and architectures are the cornerstones of next-generation telco operations, and yet we have seen very few real-world examples of genuinely autonomous live networks." [3]

Altice Labs assurance OSS suite architecture

Altice Labs has always worked closely with network and service operation centers, as our operations support systems (OSS) suite is widely used in several major TELCO companies worldwide. With the experience, feedback, and R&D that drives our path, Altice Labs has evolved over the last year the Assurance OSS suite in order to provide NOC and service operations centers (SOC) the tools they need to achieve the ultimate goal: fully autonomous operations.

The Assurance OSS suite is a modern microservices-based cloud-native platform. It can address the new challenges of elasticity and agility necessary to simultaneously support new network technologies and adapt to an always-evolving ecosystem of new network integrations and business rules adaptations. Altice Labs' Assurance OSS suite architecture is depicted in **Figure 3**.

To achieve autonomous operations, the cognitive layer powered by intelligence is the most relevant one. The following components comprise this layer:

- **KPI/KQI engine:** metrics engine with multi-vendor, spatial, and time aggregation capabilities to calculate and store thousands of key performance indicators (KPI) and key quality indicators (KQI). It allows combining different data sources and network configuration parameters to achieve metric adaptation.

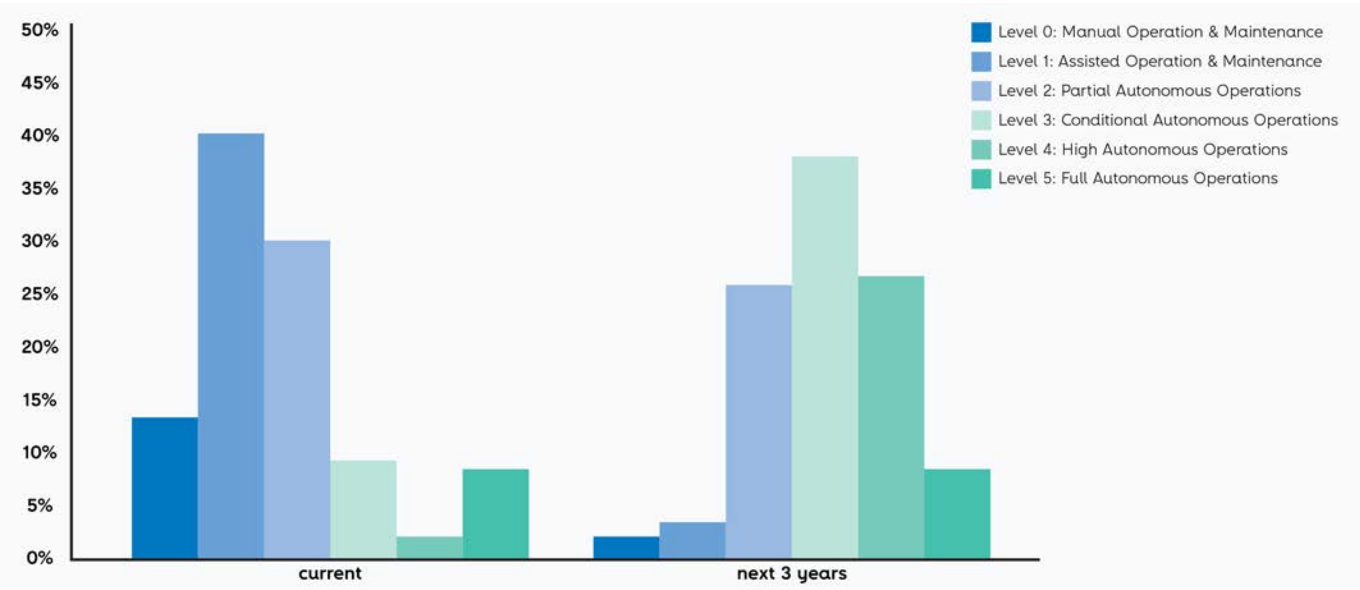

FIGURE 2 – NOC maturity level forecast

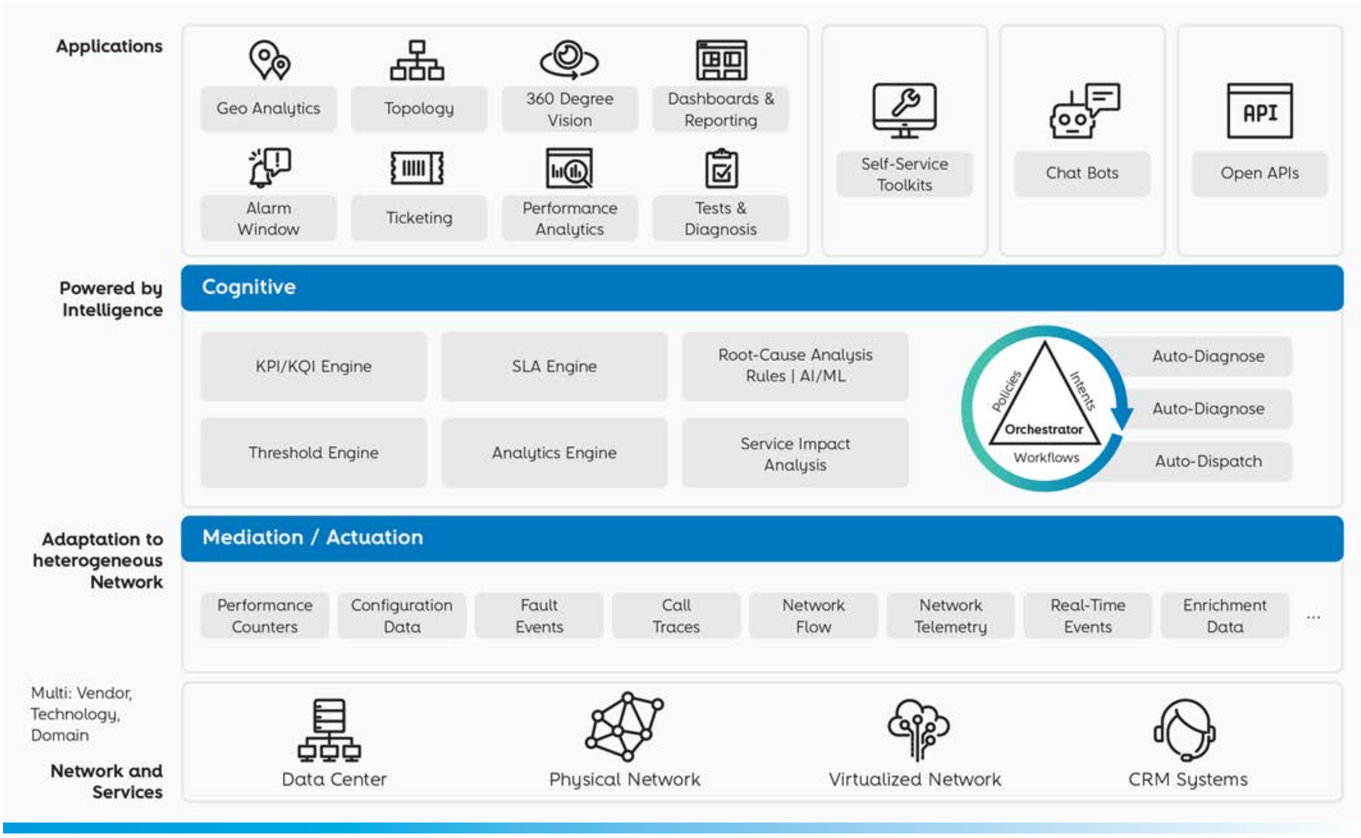

FIGURE 3 – Altice Labs' Assurance OSS suite architecture

- **Threshold engine:** from simple to intelligent thresholds that learn the usual entities pattern, identifying deviations and proactively detecting failure scenarios.
- **SLA engine:** service level agreement (SLA) management tools supporting multiple SLA types, including operational level agreements (OLA), allowing operations to monitor, control, and comply with the agreed SLA. It has the ability to automatically notify and/or escalate, functional or hierarchically [4].
- **Analytics engine:** advanced analytics with AI/ML will be pervasive in this architecture.
  - **Descriptive analytics:** it answers the question 'what is happening?' and is usually the starting point for business intelligence. Using comprehensive, accurate, and live data, it provides a clear picture of what has happened in the past.
  - **Diagnostic analytics:** once you know what occurred, you will want to understand why it happened. This is where diagnostic analytics comes in. Understanding why a trend is growing or a hassle befell will make the commercial enterprise intelligence actionable. It prevents the NOC team from making erroneous guesses, especially associated with confusing correlation and causality.
  - **Predictive analytics:** when you recognize what occurred in the past and apprehend why it happened, you may begin to predict what's possible to occur in the future - that is the goal of this type of analytics.
  - **Prescriptive analytics:** it answers the question 'what do I need to do?' and is the most complex type of analytics. By considering all relevant factors, it uses data to determine an optimal course of action, recommending the next steps.

- **Root-cause analysis analysis: the root-cause analysis (RCA) can be of two types:**
  - **Rule-based:** it is business-driven – offered services are defined by business rules.
  - **AI/ML-based:** out-of-the-box AI/ML engine with explainability features (i.e., it can describe why a decision was made in terms understandable to humans) able to detect patterns between events automatically. It can also be used to automatically and without prior knowledge or configuration detect the root-cause event that caused an outage.
- **Service impact analysis:** automatically detects a list of affected services and enriches the outage with that information. It can be automatically used prior to the automatic trouble ticket (TTK) creation to create the latter with the list of services affected by the fault.
- **Orchestrator:** enables the construction and ensures the execution of automated use case workflows, applying the policies defined by the CSP to achieve the process's objective. In real-time, it coordinates the workflow activities between different systems, such as problem management, fault management, performance management, diagnosis, and fulfillment management. It provides the following capabilities:
  - **Auto-diagnose:** execution of test commands on the network and services to assess the quality of service;
  - **Auto-healing:** application of configurations/ corrections to solve a problem autonomously and automatically, according to the objective and the established policies;
  - **Auto-dispatch:** autonomous assigned the correct team to send to the field to solve the problem.

All components can be organized to respond to various functional use cases and deliver the existing functions provided by the current OSS domains, as well as new scenarios like autonomous operations.

One of those use cases will be described more thoroughly in the next section.

Using all those features will allow NOC to reach the last maturity level: fully autonomous operations. At this level, there is no human intervention. Without human intervention, there are no human errors and no repetitive tasks. It is easy to conclude that by only having machines doing the job, the speed at which tasks can be performed is incomparably faster. In this stage, self-healing and self-optimizing improvements are part of the day-to-day operations.

The mobile network zero-unavailability use-case

Automating a problem-solving process does not necessarily imply that a correction is applied autonomously or automatically. What is intended, in many scenarios, is the recognition of the existence of a problem and the execution of a set of actions that promote its resolution and minimize the impact perceived by customers, the latter being the main driver of automation. The severity of a problem is measured by its impact on services and its cost. Any contingency action that allows canceling or substantially reducing the customers' perception of service degradation or unavailability is equally or more important than the resolution itself.

Customers' perception of service unavailability may be immediate in a radio access network (RAN) cell failure scenario. Therefore, it is crucial to ensure that the perception time interval is as short as possible and that it becomes, whenever possible, independent from the resolution time. Hence, the first action triggered in a mobile network cell failure should aim at immediate service restoration.

Based on the nature of the RAN, the same zone/ region may have coverage ensured by more than one cell as long as their orientation and range allow such overlapping. Having said this, in situations of a total site failure, according to network planning criteria, one or more cells may be identified from other sites that could be reconfigured so that their range allows them to cover the zone affected by the service unavailability. This temporary action will enable the operator to re-establish service before the problem is solved.

As shown in **Figure 4**, the automation of this process will be triggered by the reception of alarms identifying the unavailability of a cell, which will trigger a root cause analysis process and lead to the opening of a ticket for analysis by the corresponding team. Simultaneously, the availability and capacity of neighboring cells will be assessed. Suppose one or more viable neighboring cells are identified for the temporary coverage of the affected area. In that case, the selected cells will be automatically configured so that they can provide service to the affected area. Once the configuration has been changed, the performance of the selected neighboring cells must be evaluated to verify the preservation of the quality of service provided by them.

The analysis and resolution of the open ticket for the problem cell should follow its usual process. Once the problem has been solved, the closure of the respective alarm will be observed, which will automatically trigger the reset of the network configurations. Once the alarm has been closed, it will be validated whether the performance indicators of the affected cell have normalized, and if so, the respective ticket will be automatically closed and the configurations carried out on neighboring cells will be restored. After this action, and after a defined time interval, additional action is triggered to validate the performance of both neighboring cells and the affected cell (see **Figure 5**).

In this use-case, the modules of the Assurance OSS suite involved are orchestrator, root-cause analysis rules, service impact analysis, SLA engine, and KPI/

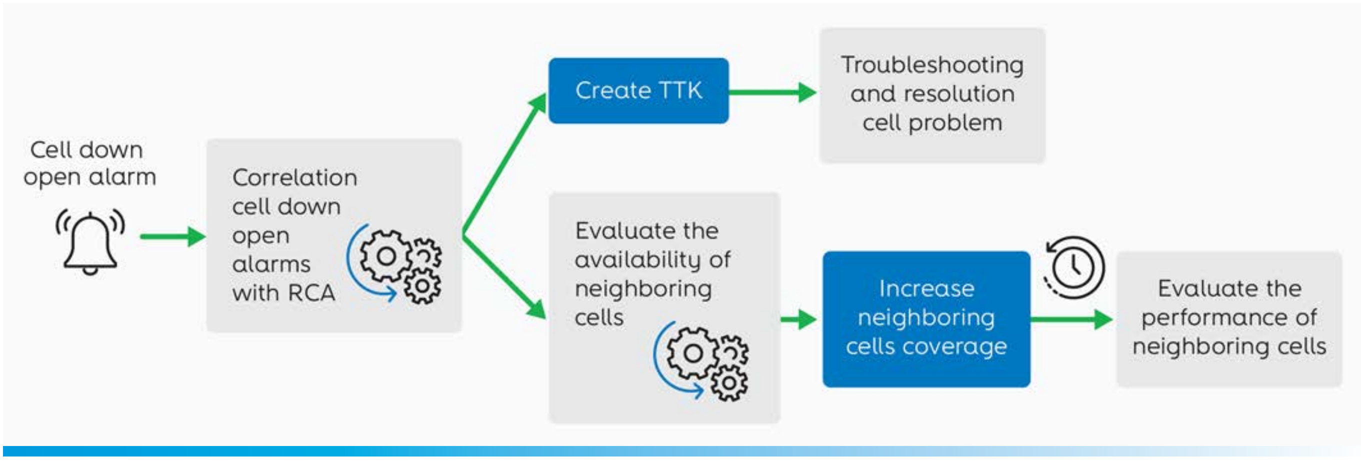

FIGURE 4 – Autonomous workflow when cell down alarm raised

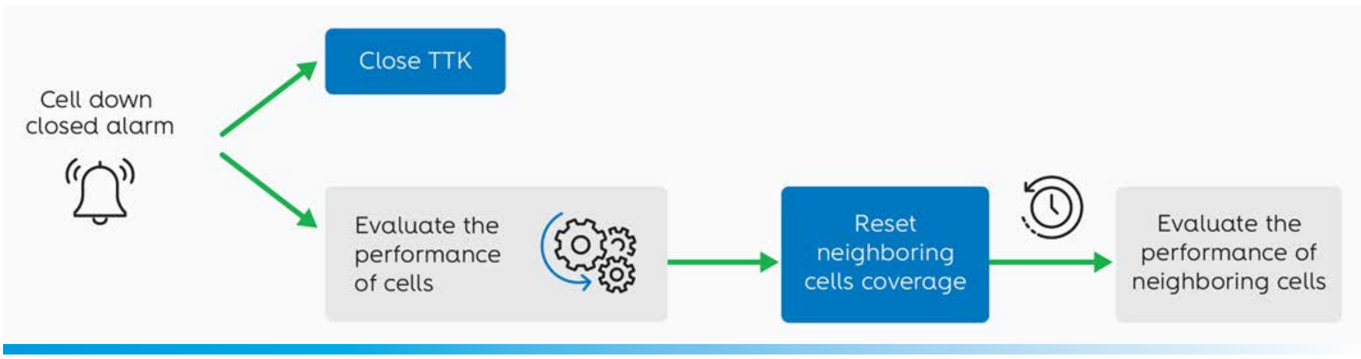

FIGURE 5 – Autonomous workflow when cell down alarm closes

KQI engine (see **Figure 6**). The orchestrator module contributes with the ability to do auto-diagnosis to evaluate the service status, auto-healing of the service, and auto-dispatch, if necessary.

Conclusions

The paradigm of telecommunications networks has changed radically, and the survival of CSP depends on their ability to change and adapt. Services will tend to be more numerous, and also more specialized and personalized. Thus, management, monitoring, and automatic action become crucial. Therefore, it is essential that each CSP defines a strategy for automation and starts on this path as soon as possible. In a highly competitive ecosystem, exacerbated by the ease with which clients can change CSP, the fastest and most efficient CSP on this transformation path will be the ones to succeed. As so, it is crucial that the top three objectives are considered throughout the process: improving overall efficiency, controlling costs, and increasing self-service. Maximizing these three vectors should be the strategic driver.

This automation process intends to be incremental and should be based on the continuous improvement of automated processes that evolve according to the CSP maturity and the results obtained. The solution for each scenario depends on its nature, so the correct characterization of each use case determines the best solution, which may be rule-based and/or AI/ML-based. The quality and availability of information are also crucial factors, and success depends on the involvement of the various areas of action and information in the CSP.

"The concept of 'Automated Assurance and Operations' encapsulates the combination of granular monitoring; multi-domain analytics; and process and network operations management capabilities – underpinned by both rule-based and AI/ML-driven automation" [5].

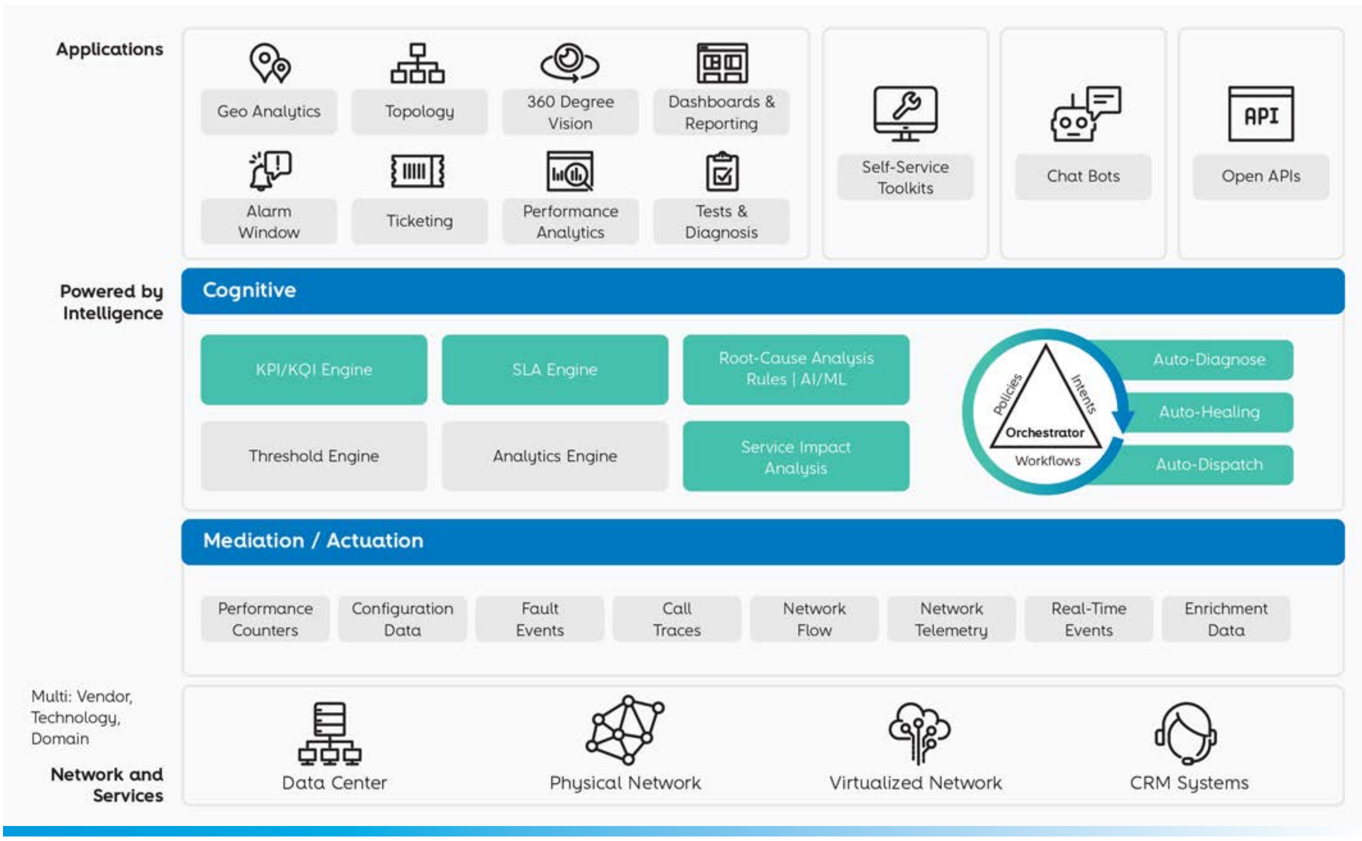

FIGURE 6 – Assurance OSS suite modules used in the mobile network zero-unavailability use-case

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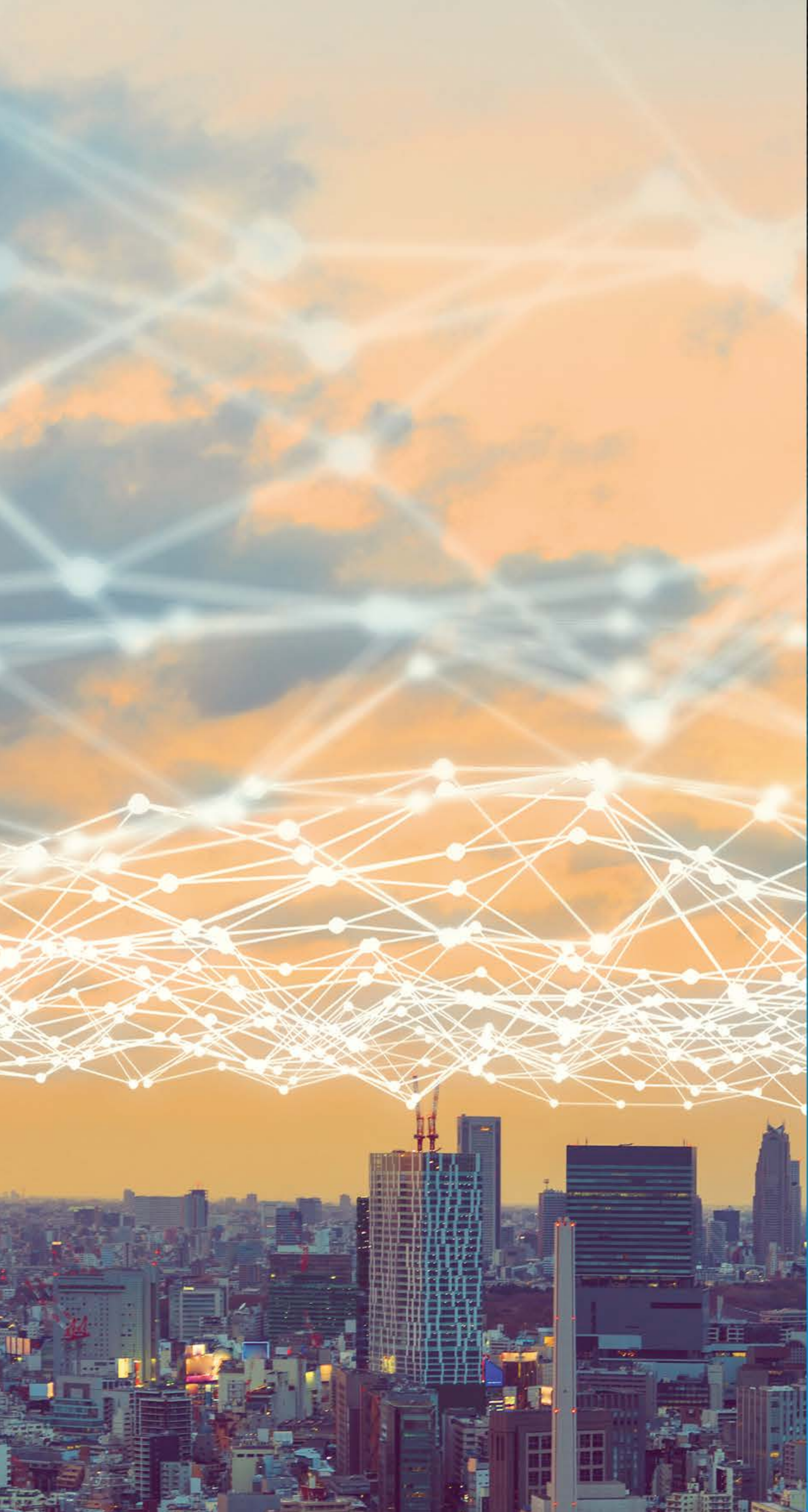

DOI: https://10.57650/innovaction/2022.09

09 Connected life: the path to a smarter ecosystem

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Connectivity still plays a significant role in the communication services providers' business, but the commoditization of the network is forcing operators to move forward and change their business approach. It is now the time to become more agile and bring new services to customers, supported by solid partnerships in the search for new sources of revenue. Altice Home is Altice Labs' home environment offering to facilitate people's living by enabling an increasingly connected life.

Keywords

Connected home; Smart home; Matter; IoT

Context

Network commoditization was one of the critical causes forcing telecom operators to change from connectivity providers toward technology companies. Operators expend high amounts of money on evolving the infrastructure. The investments in wireless technology (3G, 4G, 5G, and others), including spectrum acquisition and the shift to fiber networks, significantly impact TELCO wallets. Moreover, the business and operation support systems require evolutions to cope with the new technologies and services enabling a customer journey of excellence.

Today, connectivity is still a TELCO-based business with limited growth in mature markets. But the bet is to go beyond it and to move up in the value chain. TELCOS aim to shift from communications service providers to technology service providers (i.e., TECHCO), seeking new sources of revenue. The mindset change must appeal to technological agility supported by new partnerships that bring innovative expertise.

Following this trend, Altice Labs presented the path to a more innovative ecosystem by developing a dynamic home environment for Altice Group's product portfolio. Besides indoor connectivity, Altice Labs' solution is easy to use and integrates security, health, entertainment, and energy seamlessly.

Trends at home

Societal change

The COVID-19 pandemic changed the way people live. Despite technological advances, people's mindset has remained unchanged for years. However, the forced isolation period experienced made things possible, overcoming years of distrust!

Suddenly, most of us started working from home, changing the city dynamics. People could now work far from the urban space, reducing daily pendular movements. In this new reality, there is no place for traffic jams, and a decrease in fuel-based pollution can finally occur.

E-commerce sales increased when consumers in lockdown started buying their essential products from home. We began to shop primarily online with new consumption patterns influenced by the different routines; we made our closets into small stores to ensure that nothing essential would be missing. We can even download hardware by using 3D printers. The gym trainer became a personal avatar, the cinema is in our living room, and some special events are now experienced on the computer.

This new digital life is picking up people from all generations; it is as natural as breathing for young people. However, despite the growing digital literacy, the same cannot be said for older people. Nevertheless, supported by user experience-based systems, digital interaction can be made smooth enough to become fully inclusive, and the home will be the 'sweet home'.

Technological evolution

Information and communication technology evolution support connected life, where virtual and physical are merged in a digital world. The vast processing capacity, memory, and storage allow us to cope with the big data storm. Sensor information from internet of things (IoT) devices, the digitalization of processes, social networks, the smart city, and Industry 4.0 trends made it necessary to handle data in different formats and rhythms. Cloud computing provides dynamic resources for businesses, while edge offers the same assets for those with location requirements. The available capabilities enriched with artificial intelligence (AI) algorithms allow us to extend reality, even if indoor environments.

These technological developments impact how we live at home. Sensors and actuators are now part of our lives. The advent of low-cost devices with communication capabilities made IoT a considerable success in the home domain. Saving energy is now more manageable using intelligent smart plugs, light switches and bulbs, and simple mobile apps that can control everything. The smartphone can easily control light intensity, color, and choreography, creating a unique environment. It is now possible to detect water leaks by spreading a few devices around critical spots. Safety valves can seal to prevent further damage whenever a leak is detected. And AI, with all its flavors, allows different service offers. With the computer vision revolution, AI-based cameras bring surveillance to the next level. Technology can now identify objects, persons, events, or situations. These capabilities significantly impact the correct functioning of the security system by avoiding raising false alarms and confusing a bird with a robber. Voice-based devices are changing the way we interact with objects. Supported by advanced algorithms, smart speakers allow relating with devices on distinct levels of interaction. Basic versions of these devices can understand a simple set of commands, enabling specific equipment control. But they are now becoming personal assistants, controlling more than devices, even reaching the management of the daily schedules. Amazon and Google personal assistants are invading homes and do not seem to be in the mood to move anytime soon.

Matter: the unifying smart home standard

Despite all technological evolution, smart home adoption is slow due to a lack of universal standards. As soon as end-users start their smart home brave journey in some ecosystem, it will be very difficult to join other ecosystems to fully benefit from all potential smart home capabilities due to the vendor-lock effect. On the other hand, there is engineering/cost overhead for device makers to support and certify their devices for multiple ecosystems.

Matter [1] is an emerging Connectivity Standards Alliance (CSA) standard that aims to fix these problems. Matter is being adopted by all major players of the smart home ecosystem, including Amazon, Apple, Google, Comcast, Tuya, Samsung, etc. The Matter standard aims to be a seal of trust for end-users by ensuring that devices securely work seamlessly together and can be controlled by any Matter-enabled application and voice assistant/smart speaker.

The Matter protocol is designed on top of a universal IPv6-based network infrastructure. The first version supports Ethernet, Wi-Fi, and Thread networks, while Bluetooth low energy (BLE) is used to commission new devices. In Matter, Thread [2] is the recommended protocol to be used by low-power devices. Like ZigBee, Thread operates in the 2.4 GHz band but can natively work on top of a Matter IPv6 network with an open application layer. A Thread border router network functionality is needed to interconnect Thread with Wi-Fi and Ethernet sub-networks, but multiple Ethernet sub-networks can co-exist in the Matter network (see **Figure 1**).

The multi-domain concept is one of the most promising Matter concepts by enabling device sharing on multiple ecosystems, which means that the same device can be controlled by different applications and voice assistants. To securely interact, devices must be in the same security domain: the Matter fabric. Thus, the multi-domain concept implies that each device can be in multiple fabrics.

The initial Matter specification was released in early October 2022, and the first Matter devices should be available before the end of 2022.

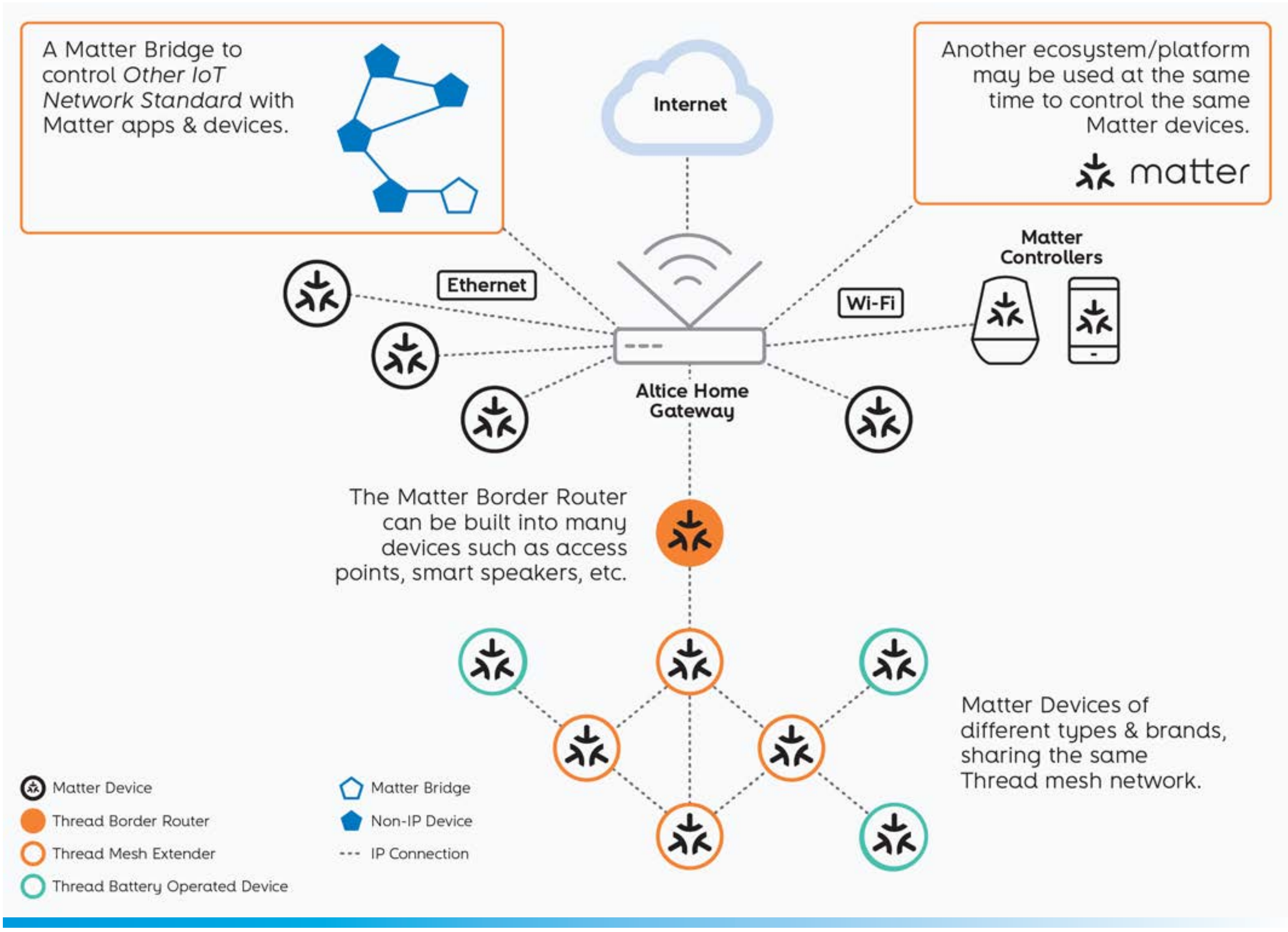

FIGURE 1 – Matter network topology

Altice connected home

Altice Home [3] aims to be a key solution to create new sources of revenues for TELCOS by providing not only the traditional smart home services (e.g., remote monitoring and management of connected devices and systems) but all services potentially delivered by TELCOS to residential customers, including smart connectivity and smart energy management. Although the solution targets residential households, it can also target smart office and smart building markets. In the end, Altice Home aims to be the focal point of service delivery to residential, as well as small and home offices (SOHO) or small and medium enterprises (SME) segment markets. It is designed to be agile and to evolve quickly according to market demand, new business opportunities, and breakthrough technologies. Despite the complex ecosystem of technologies and business goals, Altice Home is human-centric. Anyone can benefit and make the most out of it. No one is left behind by promoting, from the very beginning, digital inclusion and equitable access to all Altice Home benefits.

Considering the wide range of technologies and the level of complexity needed to implement and maintain a complete and innovative smart home solution such as Altice Home, it is critical to adopt a strategy to ensure the product's self-sustainability in a market where big players, like Google and Amazon, are fighting to lead. Altice Home does not aim to compete with the big smart home ecosystems directly but to support as much as possible all major ecosystems and to integrate with some of its advanced features, like AI-powered voice assistants, and leveraging some TELCO key assets to differentiate from other smart home service providers, such as:

- Customers not having to purchase and install dedicated smart home hubs since the Altice Home gateway provides all the connectivity features needed to support Matter standard-compliant home devices.
- Better customer support, since TELCOS are best positioned to troubleshoot customers' connectivity issues and to provide local services such as on-site assistance and installation.
- Privacy and personal data management, as TELCOS are more trusted in this capability.

Altice Home features

The Altice Home solution is a turnkey connected home solution where the ease of use and integration turn customers' houses into an extension of their way of life. Examples of included core features are:

- Device management, which includes onboarding, setup, device status management, and device control.
- Real-time device monitoring and telemetry.
- Multiple homes management, to allow users to control devices from different houses with the same smart home account.
- Users' management to control users' access to smart home features and devices.
- Alerts and notifications to keep users informed about the most relevant events, including occurrences that may require immediate attention, like intrusions or fire alerts.

Automation is at the core of Altice Home's solution and is based on the scenario concept. Scenarios allow users to set conditions (including voice commands, device-triggered events, and time-of-day events) and automatically execute one or more actions on the home environment by creating new and personal applications for their smart devices. These may be, for example:

- 'Movies Night' scenario – dim the lights when the smart set-top box (STB) starts playing and turn the lights back on when he pauses the movie.
- 'Welcome home' – a pre-configured scenario that occurs whenever one arrives at home.
- 'Lights on' – set the lights to turn on when someone enters the room and to turn it off when leaving.
- 'Good Night' scenario – the user sets up what happens when he goes to bed (e.g., turn off his bedside lamp and turn on an exterior light or the one in the hallway).
- 'Good morning' scenario – the user programs a set of tasks to take place when he wakes up, like turning on the bedside light while the Altice butler salutes him.

On top of Altice Home's core features, different types of user needs are supported by several kinds of devices, grouped into packs (addons).

The **Comfort pack** includes a comprehensive set of low costs devices that are easy to install and set up using the mobile app, including smart lights, smart plugs, and IP cameras (as shown in **Figure 2**).

The **Smart Security pack** provides key information about different types of physical threats and risks in the household, like intrusion, fire, gas leak, and carbon monoxide detection. When potential risks are detected, emergency alerts and warnings are triggered (e.g., smart sirens), and the user is notified through different channels, including push notifications, SMS, and voice calls. The storage of the videos recorded by IP cameras in the cloud is a premium feature of this pack. **Figure 3** shows some security devices associated with this pack.

FIGURE 2 – Altice Home comfort devices

FIGURE 3 – Altice Home security devices

The **Smart Connectivity pack** is a key differentiator between Altice Home solution and other connected home offers, by leveraging the full control of the home network with a set of functionalities, including zero-touch devices setup, prevention of connectivity issues, and a fully protected home network from cyberattacks. Furthermore, it allows the management of all kinds of connected devices at home, including non-IoT devices, and full internet access control.

The **Smart Energy and Sustainability pack** is designed to enable energy consumption savings at home and reduce, in general, the household carbon footprint. It includes an energy dashboard displaying the energy consumption and energy production information, and a set of advanced features to optimize energy management, such as automating the start and stop of highly energy-consuming activities (e.g., laundry, dishwashing, and electric vehicles chargers) according to the most convenient and cheaper time of the day.

The **Entertainment pack** allows the management of entertainment services in the home, including STB and associated remote control devices, as well as making it more fun with the playback of music or video in scenarios' configuration.

The **Wellbeing pack** includes continuous and real-time care of all household members, notably elderly and children care. It sends alerts to the caregiver when some anomaly is detected about an elderly or sick person.

A single app strategy ensures the best service possible in a single place, including the control and status of all types of connected devices, and a richer set of automation by having centralized access to all kinds of events and capabilities.

Altice Home architecture

The Altice Home system is built upon a micro-services-oriented architecture, applied in a smart home as a service delivery model which can be hosted on public or private cloud infrastructures. Altice Home is a multi-tenant solution where more than one TELCO operator can use the same instance of it. Each tenant can be spread across different regions to improve service and data locality, and comply to regulatory issues. Moreover, the system is designed to have weak dependencies on TELCOS' OSS and BSS systems, notably identity providers and provisioning systems.

The overall global high-level architecture is represented in **Figure 4** (on the next page), where the major functional elements are highlighted:

- Open API services – exposes the northbound API to be used by the different client apps, including mobile apps, customer care portals, OSS/BSS systems, and voice assistants.

- Smart home core – comprised of different microservices, message brokers, and data persistence implementing business logic to handle IoT devices. Major smart home microservices are home and customer inventory, devices and services inventory, home configuration manager, device automation manager, analytics, back-office, identity and access management, etc.

- Smart connectivity element – based on Altice Labs' smart mesh Wi-Fi cloud management solution to control the home gateway, Wi-Fi extenders, and all devices connected to the home network. It provides home network cybersecurity features, including device recognition, network and browsing protection, etc., as well as advanced smart connectivity features like parental control and traffic prioritization.

- IP camera services – provide advanced video-related services for IP camera devices, including live-stream session management, cloud video recordings, storage for audio/video (AV) recorded files, AV stream server to manage playback sessions of recorded AV files, encryption keys management, etc.

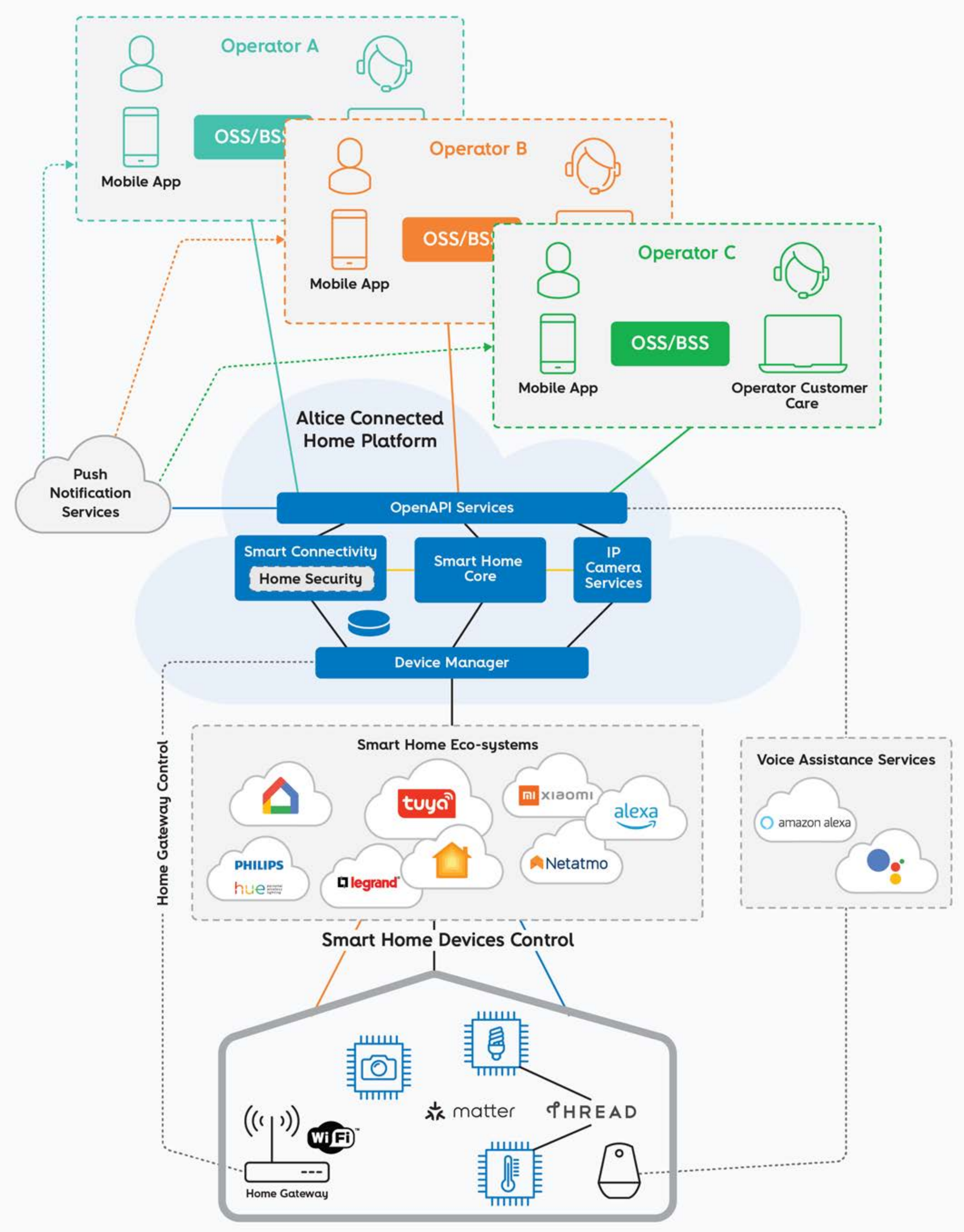

FIGURE 4 – Altice Home high-level architecture

- Device manager – handles device registration and over-the-air (OTA) firmware management consistently across IoT and non-IoT devices. Smart home device manager comprises a multiprotocol adaptation layer to facilitate the integration with smart home ecosystem clouds like Tuya and Phillips Hue.

Altice Home applications: mobile app and customer care portal

Altice Home's applicational solution comprises two main front-end applications: the mobile app, to be used by end-users, and the customer care portal, to be used by the Altice Group operating companies to support end-users. More applications are planned, including end-users applications to run on web browsers, smart displays, STB, and smart TVs. Altice Home user experience (UX) designed for these applications focuses on what is essential to ensure end-users will not get lost in the set of available features.

The mobile app plays a crucial part in the user journey into Altice Home. This app is a unique control platform that offers a complete overview of the connected home, as well as full control of all smart devices. The experience is designed to be unique and available across devices and platforms, from mobile (Android and iOS devices, as shown in **Figure 5**) to voice command devices and TV, in the future. An integrated vision and unified experience is provided to control all the devices and systems.

The customer care portal, depicted in **Figure 6** (on the next page), is critical to differentiate Altice Home from other connected home products. It is designed to be used by customer care agents, technical back office, and business analysts. The portal is a unique control platform for operating companies, offering a complete overview of the customer's smart home environment and full control of his smart devices. It provides features to manage customer accounts, premium features subscribed, the different homes in the account, and all devices in each home. The customer care portal also provides a firmware manager tool and EU GDPR management, supporting various business KPI and business analytics reports.

FIGURE 5 – Altice Home mobile app

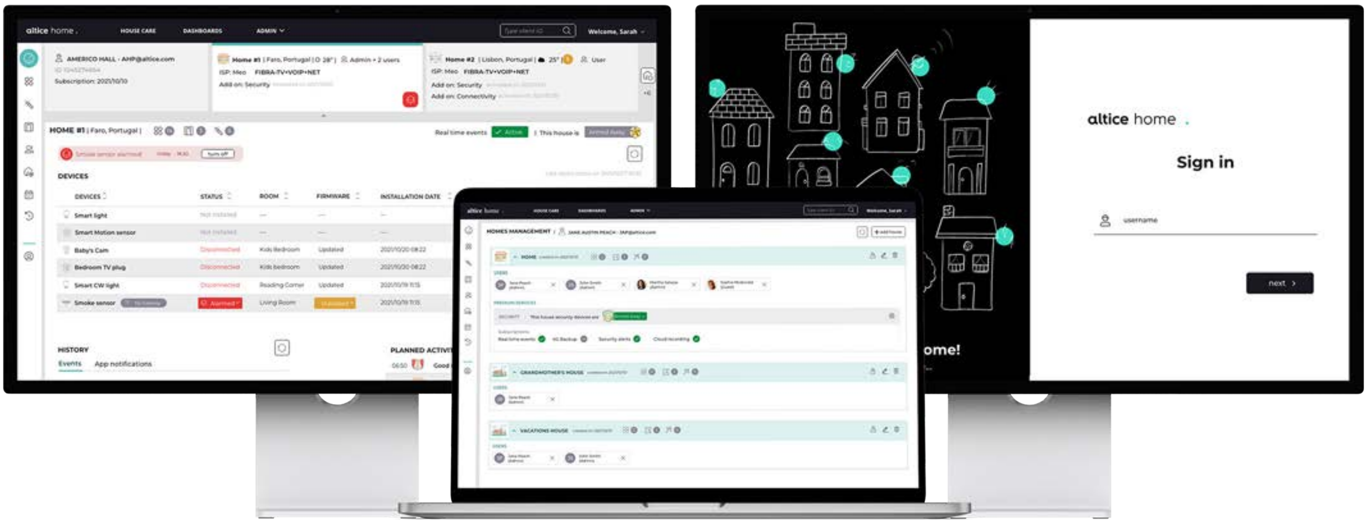

FIGURE 6 – Altice Home customer care portal

Conclusions

The societal changes and technological evolutions opened the doors to new ways of life, where the digital is now the glue between physical and virtual environments. More intelligent ecosystems will appear, making available innovative services running on top of the evolved connectivity.

TELCOS need to adapt to this new world and lead the change. To streamline the business and optimize operations, all lead to believe that the transformation will be made towards the technological companies' model. It is critical to ensure technical agility while creating new partnerships to bring innovative expertise. Enriching the TELCOS catalog by quickly adding new digital-based services supported by enhanced networks is mandatory.

In this path, Altice Home encompasses all services potentially delivered by TELCOS to residential home customers, including smart connectivity and intelligent energy management, ensuring agility and fast evolving according to market demand, innovative business opportunities, and new technologies. To achieve this goal, Altice Home is embracing Matter as a key technology to drive Altice Group towards an innovative TECHCO ecosystem.

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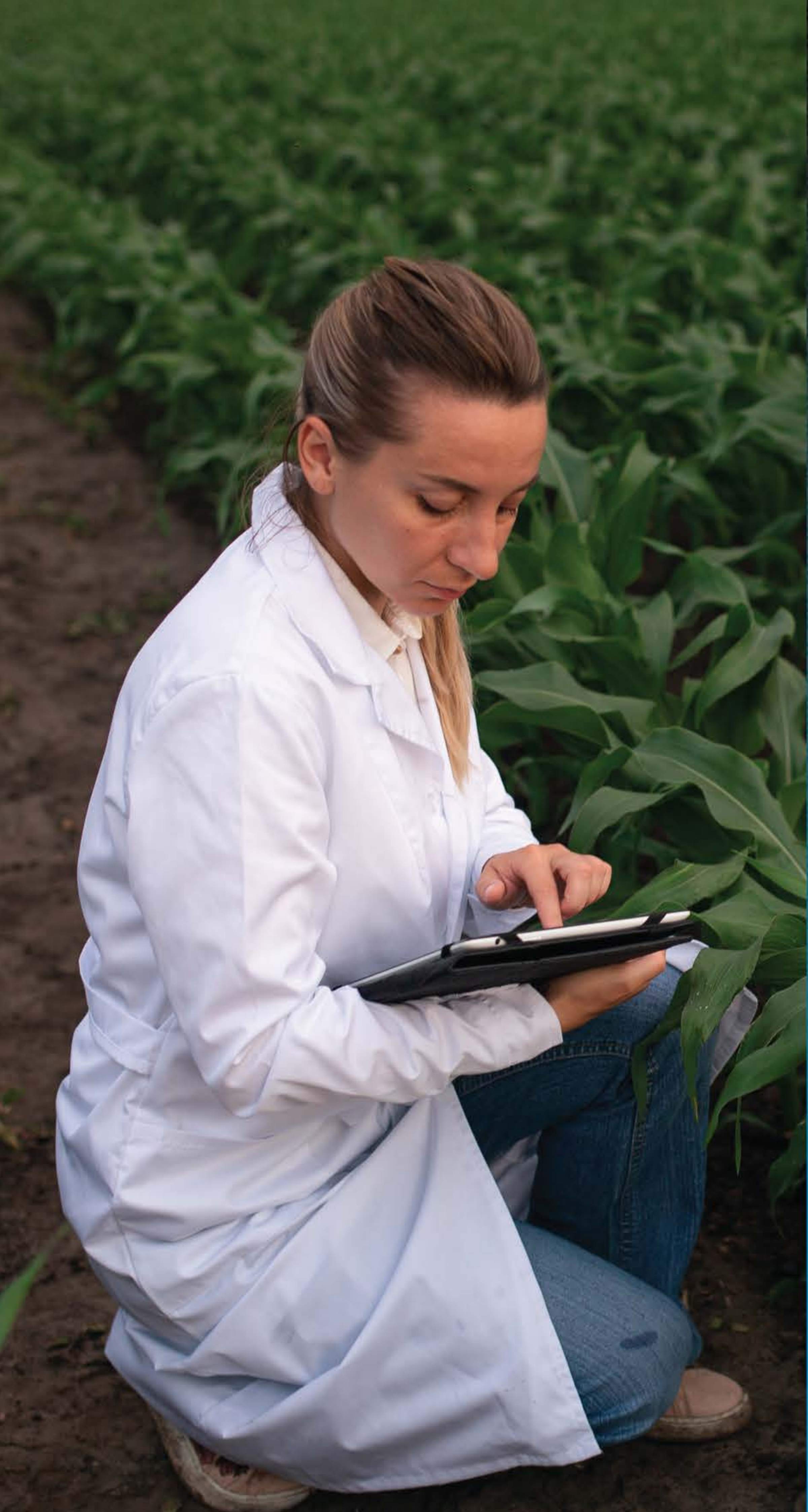

DOI: https://10.57650/innovaction/2022.10

10 Agrotech – sensing use cases

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The agrotech revolution is emerging and aims to use advanced precision technology, such as real-time analysis o soil nutrients and weather conditions using sensors to meet the future demands or ood in a more sustainable, efficient, and eco-riendly way. IoT is remodeling agriculture, enabling armers with a wide range o techniques, namely precision and sustainable agriculture, to ace challenges in the field. On the other hand, using artificial intelligence paves the way for farmers to optimize production and minimize resource utilization. A practical example o using IoT technology and machine learning models is described in this article or the banana crop in Madeira Island.

Keywords

IoT; Agrotech; Machine learning; Banana crop; Service platorm

Introduction

Agriculture is changing, and innovation is more important than ever. Farming agriculture is facing huge challenges, from a labor shortage, supplies rising costs, and changes in consumer preferences such as food traceability and food safety [1]. New precision agriculture and the implementation of developing technologies are extremely important to farmers to maximize their yields by controlling important variables of crop farming, such as moisture levels, soil conditions, fertilization levels, and micro-climate changes.

In Madeira island, banana cultivation has a major impact in several areas, such as economic, social, and environmental, and in the region's landscape, with its commercialization growing over time [2]. Currently, the banana business moves millions of euros to the region and employs thousands of people on the island [3]. Since Madeira has many singular producers of bananas, there was a need to create an organization that manages the production, collection, and distribution of the banana to be a sustainable and continued business [4].

The Banana Sector Management Company of Madeira Island (GESBA) was founded in 2008. While seventy percent of the bananas on the Island are produced in the summer, only thirty percent are in the winter. Therefore, the large volume of production in the summer ultimately affects the market values. So, the company's main aim is to improve bananas' quality and market value.

GESBA recognizes that new agriculture solutions are needed to face these challenges. In collaboration with the University of Madeira (UMa), Regional Agency for the Development of Research, Technology and Innovation (ARDITI), Altice Labs, and Altice Portugal, GESBA is sponsoring an ongoing project named 'BAnana SEnsing' (BASE), approved and co-founded by 'Programa de Desenvolvimento Rural da Região Autónoma da Madeira' (PRODERAM 2020), Regional Government of Madeira, Portugal 2020 and by the European agricultural fund for rural development (EAFRD). The BASE project started on 1 July 2022 and will end on 31 March 2023. This project will bring significant technology innovation practices to the banana sector by applying sensor technology to monitor the crop growth of banana cultivation in the field.

Using of IoT technology

The agrotech revolution is emerging and aims to use advanced precision technology, such as real-time analysis of soil nutrients and weather conditions using sensors to meet the future demands for food in a more sustainable, efficient, and eco-friendly way [5].

The internet of things (IoT) is remodeling agriculture enabling farmers with a wide range of techniques, namely precision and sustainable agriculture, to face challenges in the field.

IoT technology enables collecting information about conditions like weather, moisture, temperature, and soil fertility, helping farmers increase yields and have better crop management.

There has been a significant rise in research and development of precision agriculture technologies to monitor pH, salinity, moisture content, organic matter, and texture. However, in situ monitoring of soil macronutrients, nitrogen (N), phosphorus (P), potassium (K), and other nutrients remains a challenge. Moreover the sap flow sensors for banana plants are under the research domain.

The BASE project has deployed a set of IoT sensors in two sites with different climatic and edaphic conditions (Ponta do Sol and Lugar de Baixo sites), where the development of a representative sample of banana plants is monitored using morpho-agronomic traits during three phenological stages, shown in **Figure 1**.

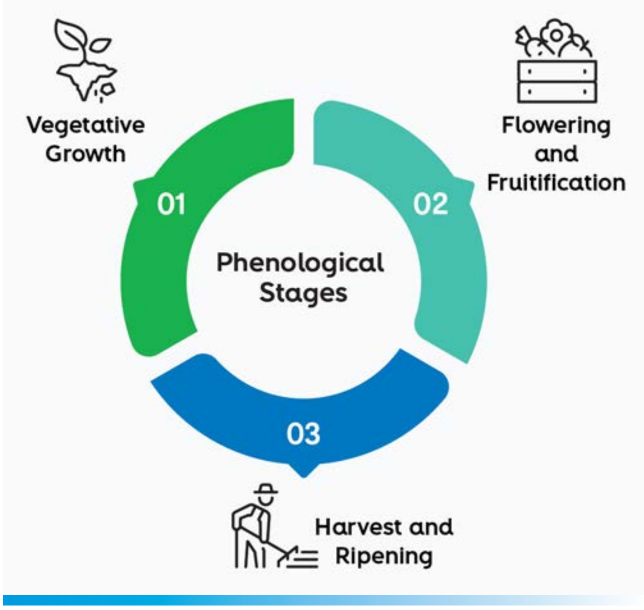

FIGURE 1 – Phenological stages

To perform these studies, the cultural practices, irrigation, and fertilization management of the banana plots are recorded in the field using a cloud monitoring platform.

The project has successfully implemented this monitoring platform able to collect a set of soil, weather, and leaf parameters with near real-time updates that are also of extreme importance since the stored data can provide historical values of those parameters for future studies.

Having this technology applied to the field is of the utmost importance in understanding how to increase crop yield, especially under different weather and soil parameter conditions.

The overall system architecture is presented in the next section.

High-level system architecture

The overall system architecture designed for the project is represented in **Figure 2** and is divided in four layers:

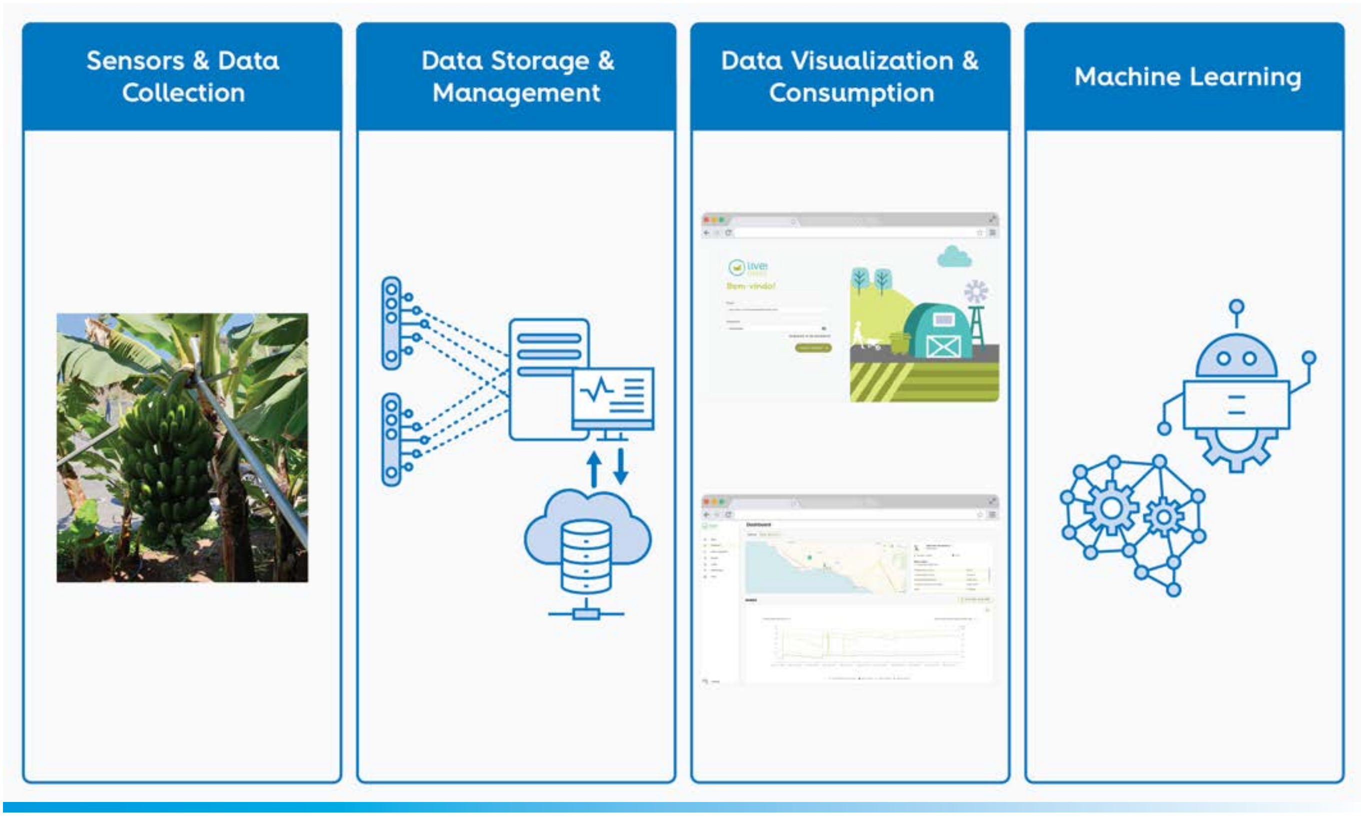

FIGURE 2 – High-level system architecture

1. Sensors & data collection: In this layer, the system collects data from several types of sources. Banana plants have sensors to measure several parameters from air and soil, which communicate with the data storage & management layer through the gateway adapters using a SIM card with 4G mobile data. The user may also insert morpho-agronomic data collected manually.

2. Data storage & management: This is the layer where the data is transformed and stored in Altice Labs' Live!Data service platform [6]. This platform consists of a backend server and several gateway adapters that communicate with the sensors, receive the data, validate it and parse it into a format compliant with the database. The backend server exposes an API to retrieve the data, get analytics, and process the data.

3. Data visualization & consumption: Altice Labs' Live!Green application, which runs on top of the Live!Data service platform, provides the user with a dashboard where it is possible to see the last values read by the sensors, some historical information, and the geolocation of each sensor. In this dashboard, the user can compare the values read by the sensors over time and analyze the historical information to make the best decisions and learn from the data collected. Another feature available in this platform is that the user can write the readings of each state about the morphological data and store photos from each plant in the field. Also, in this layer, authorized entities may access the data through a representational state transfer (REST) API from the backend server (in the middle layer). The data is available in JavaScript object notation (JSON) format or as a comma-separated values (CSV) file.

4. Machine learning: This layer is responsible for recognizing patterns and getting hidden knowledge from the data stored on Altice Labs' Live!Data platform, and for predicting events from the data collected. This layer is where the user will get the benefits from the work and the investment in the previous layers (sensing, storing, and displaying the data). Data is read from the data storage layer and processed with adequate machine learning algorithms to retrieve knowledge from it. This layer is being developed in partnership with the University of Madeira (UMa): LARSyS [7] and ISOPlexis [8].

Sensors & data collection layer

To monitor the development of the banana plant, a set of deployed sensors can read soil and climate parameters. To gather this information, the sensors connect to a 4G communication node (namely, the Waspmote Plug & Sense! Smart Agriculture Xtreme [9]) to transmit data to the Live!Data service platform.

These sensors and nodes are deployed in two sites: Ponta do Sol and Lugar de Baixo. Each site has four communication nodes with the following connections:

- One node is connected to a MaxiMet GMX-240 weather station [10], providing the following climate air parameters: air temperature, air pressure, air humidity, wind direction and speed, and total precipitation and precipitation intensity.

- Each one of the other three nodes is connected to the following sensors:
    - The TEROS 12 soil sensor [10] provides the following soil information: soil temperature, electrical conductivity, dielectric permittivity, and volumetric water content;
    - The NPK sensor [11] provides information about nitrogen, phosphorus, and potassium;
    - The Pythons 31 leaf surface wetness sensor [10] simulates the behavior of a plant leaf, where it is possible to gather the humidity information from one leaf.

Data from the above sensors are fed automatically into the service platform.

Besides this sensing data, conventional laboratory methods, such as the manual collection of morpho-agronomic data, can be uploaded to the

Vegetative Growth	Flowering and Fruitification	Harvest and Maturation	Nutritional Evaluation
• Pseudo-stem height • Diameter of the base of the pseudo-stem • Perimeter of the middle third of the pseudo-stem	• Flowering time • Number of fruits in the bunch • Peduncle length	• Crop cycle • Number of hands • Number of fruits/ hand • Fruit length • Fruit diameter • Fruit weight • Bark thickness • Pulp color at ripening • Texture	• Ripeness coefficient • Water content • Total minerals • Crude fiber • Sugar content • Protein content

TABLE 1 – Morpho-agronomic data classification

service platform. This morpho-agronomic data is classified into three different development stages and nutritional evaluation, shown in **Table 1**.

In this study, the plant development in the different phenological stages uses a statistically significant number of plants (n=40). Photos from each banana plant are taken regularly and uploaded to the platform for analysis.

To develop a robust growth model for the Madeira banana plant, it is necessary to evaluate two production cycles of the banana crop in two edaphic conditions (summer and winter periods).

Data storage & management layer – Live!Data service platform

Altice Labs' Live!Data is the service platform that gathers data from various sources and provides several tools to enrich, process, and get analytics of the data collected. This platform serves different sectors such as industry, agrotech, smart cities, etc.

The platform has virtual representations of the actual sensors that allow the users to manage the devices and organize the information to send through the API. It also enables the user to collect processed data such as averages, maximums, minimums, etc.

Data visualization & consumption layer - Live!Green application

Live!Green is an end-user application providing data management and visualization tools for data gathered from the Live!Data underlying service platform.

Figure 3, on the next page, depicts the main page of the Live!Green application, showing each site location, Ponta do Sol and Lugar de Baixo, represented by a circle with the number of nodes inside each circle.

After choosing a given site, detailed information is presented to the user within all the different site nodes. By selecting each node, it is possible to get all values from all the sensors present on this node, within a given time slot (see **Figure 4** on the next page).

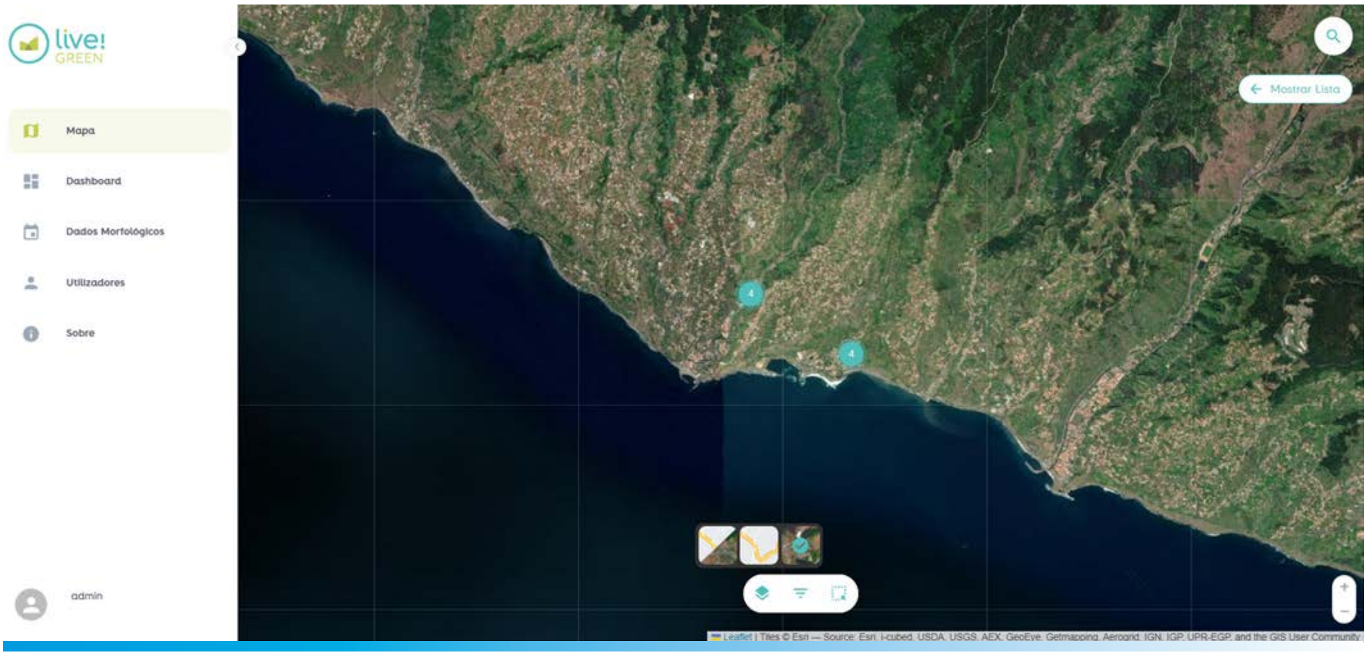

FIGURE 3 – Sensors location in the two sites

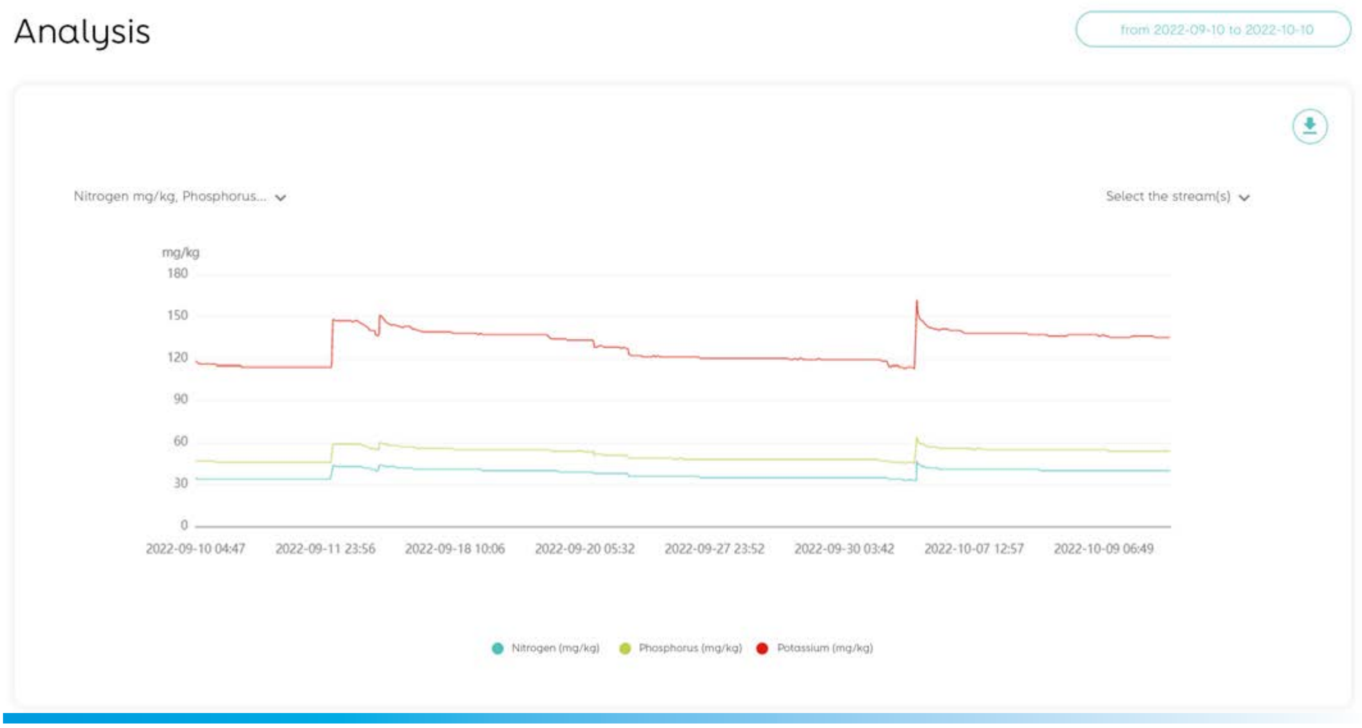

FIGURE 4 – Graphic with sensor comparisons

Machine learning layer

The sensing of the banana plantation, and collecting and storing this data in the Live!Data platform allowed the use of machine learning techniques to analyze and study the data collected during the growth of bananas. Two approaches using data-driven and machine-learning techniques were developed for analyzing banana cultivation.

The first approach considered a long period of tracking to identify which factors can contribute the most to banana maturation and to assess which information in the data can be used to follow the development of the banana bunches. For this purpose, the developed model was based on examining the data collected by the sensors, used as features to be fed to a machine learning model. When the banana bunches are harvested, the sensor's data will be used to backtrack the changes over the months to determine which information correlated the most with the maturation period of the banana. For this purpose, the feature selection procedure will be used to determine the most relevant sensor while removing redundant information, reducing the total number of needed sensors. Afterward, a heuristic optimization procedure will be employed to optimize the regression model architecture. As the volume of data is limited to only one banana maturation cycle, the use of conventional machine learning models is needed, testing different methodologies to determine which is more suitable for this problem. Subsequently, the developed model will be connected to the Live!Data platform to allow forecasts to be available for the user. The combination of both machine learning and the Live!Data platform potentiates the examination capability in agrotech. The proposed methodology is presented in **Figure 5**.

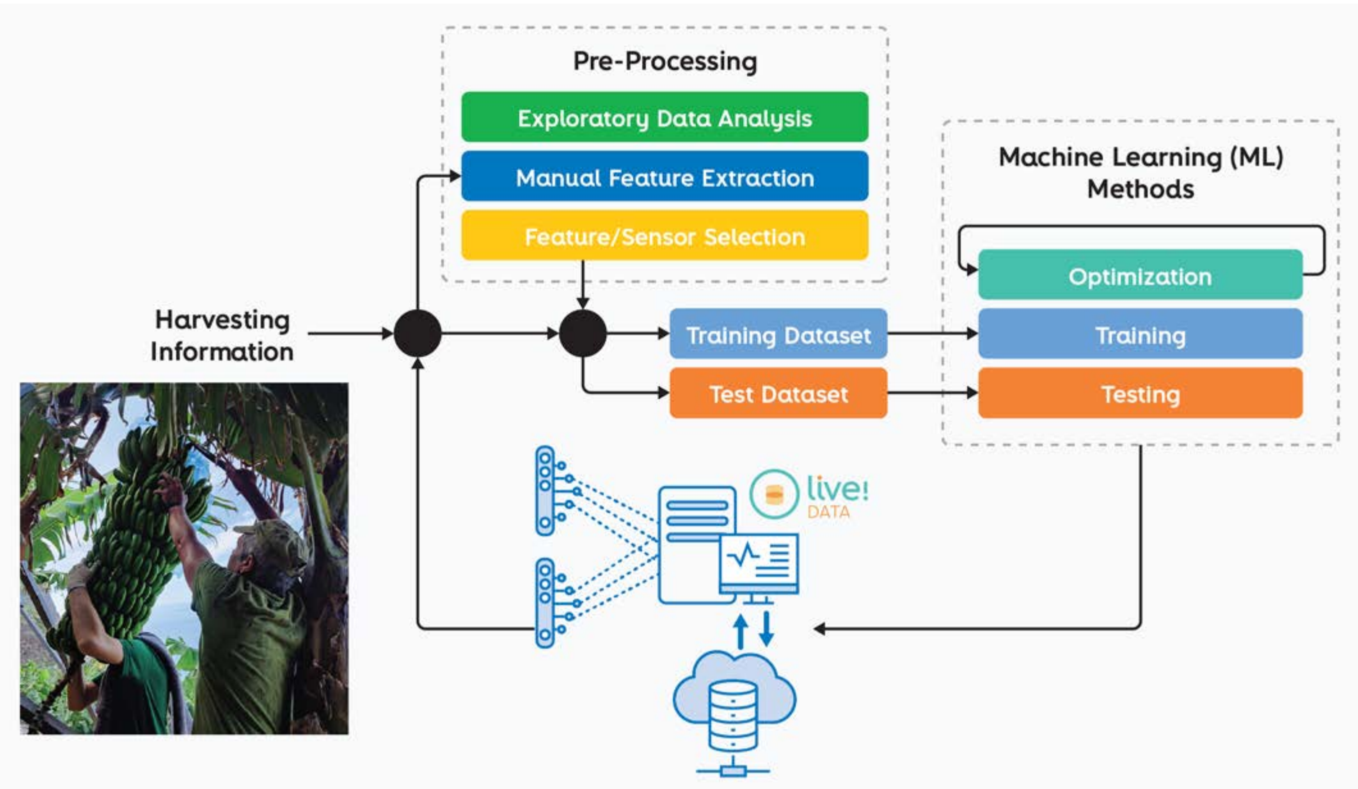

FIGURE 5 – Developed procedure for automating the banana maturation prediction using a combination of machine learning and data from the Live!Data platform

The second approach aimed at creating a contactless tool to help identify the banana harvestability and automate the banana analysis.

The central concept was segmented into three steps:

1. Target detection, where the goal was to identify the banana bunch in the images successfully. Such was accomplished using a machine learning model trained for object detection, isolating the image pixels corresponding to a banana bunch.
2. Identify the harvestability of the bunch by consulting the expert opinion, leading to the production of a second dataset, where each bunch was labeled with a unique number. This second dataset was then used to build the primary machine learning classifier, which evaluates the harvestability of the bunch.
3. Implement both machine learning models in a smartphone application, capable of automatically identifying the banana bunches and detecting their harvestability.

The proposed methodology is presented in **Figure 6**.

FIGURE 6 – Procedure developed to automate banana analysis

Preliminary conclusions and future perspectives

Food and agricultural companies are increasing investments to integrate IoT solutions in some of their processes to cut down costs, increase the quality and quantity of the harvest, and improve some of the routine activities of the farmers. IoT leverages farmers to get connected to their farms from anywhere and anytime.

By using IoT technology, the BASE project aimed to develop the application of precision agriculture technologies to control the banana production cycle, allowing the decision-maker to manage the harvesting time point with precision. The project oversees the existence of field agronomic essays and quality analysis to validate the information obtained through sensors, evaluation of crop water requirements, and data analysis. Although conventional laboratory methods may offer highly accurate analysis of soil chemistry, in situ-based soil nutrient sensors that provide real-time feedback are needed to indeed increase farming and environment management efficiency.

Altice Labs' cloud Live!Green application enables users to visualize and analyze data as a first demo of the future product, allowing them to identify critical issues and help them make decisions. It is, therefore, possible to obtain and manage knowledge about precision farming with remote sensing applications in banana crops. The deployment has also allowed us to identify and characterize two concrete plantain crop areas thanks to the wireless sensor network.

Users will save time in the field since they do not have to physically access the work field whenever they need to check something. Compared to conventional lab instruments for soil nutrient analysis, in situ-based sensors are more advantageous due to their low-cost and high-density measurement capability for large-area soil nutrient mapping.

FIGURE 7 – Morpho-agronomic evaluation of banana plants

For the morpho-agronomic data, preliminary results showed good phenological evolution of the banana plants in the vegetative growth stage (**Figure 7**). It is expected that this behavior will be maintained in the other stages.

The data of other phenological stages is required to highlight a draft of the first model of banana plant development. Additionally, the water and irrigation requirements of banana plants are also under study. The banana water balance was calculated through evapotranspiration by the Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith equation [12] (**Figure 8**).

Preliminary meteorological data highlighted the need for an adequate irrigation supplement for the plantation to support the plant's growth and development and achieve an adequate management of water resources.

On the other hand, using artificial intelligence paves the way for farmers to optimize production and minimize resource utilization. The project

$$ET_0 = \frac{0.408\Delta (R_n - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1+ 0.34u_2)}$$

Legend

ET_o - reference evapotranspiration (mm day^{-1})
R_n - net radiation at the crop surface (MJ m^{-2} day^{-1})
G - soil heat-flux density (MJ m^{-2} day^{-1})
T - mean daily air temperature (°C) at 2m height
u_2 - wind speed at 2m height (m s^{-1})
e_s - saturation vapor pressure (kPa)
e_a - actual vapor pressure (kPa), based on relative humidity measurements
$(e_s - e_a)$ - saturation vapor pressure deficit (VPD) (kPa)
Δ - slope of the vapor pressure curve (kPa $°C^{-1}$)
γ - psychrometric constant (kPa $°C^{-1}$)

FIGURE 8 – FAO Penman-Monteith equation

gathers and compiles information on other variables that influence growth, production, and fruit maturation to elaborate the Madeira banana growth model, allowing the usage of machine learning algorithms and predictive analytics to foresee when banana fruit will reach maturity.

This approach of using machine learning based on image analysis for banana harvesting is brand new and allows the examination to be carried out in a non-destructive way. The machine learning model was based on transfer learning, using a pre-trained deep learning model developed using millions of images to optimize its capability of image-based feature extraction. Therefore, by using transfer learning, the problem associated with the need for extensive data volume is lessened, allowing the development of the model with fewer images.

Hence, this automation proposal aims to improve and standardize laborers' work, saving this domain knowledge to real industry experts and preserving the knowledge by making machine learning models and a continuously growing dataset.

Potential future challenges and development directions have to do with improving data reliability, given that the banana production cycle is around 12 to 14 months and the project lasts 18 months.

Thus, it is essential to consider at least two banana growth cycles to collect as much data as possible to ensure that machine learning algorithms are fed with a large number of datasets.

Another improvement for the project is correlating ferti-irrigation data with other data in the Live!Data platform to have better knowledge of the nutrients necessary for improving banana plants' productivity.

Moreover, it could be helpful to use sap flow sensors in this study, as sap flow measurements may be a sensitive and accurate method to determine the whole-plant water and nutrient needs during banana plants' development. The correlation of this data with the agroecological conditions of the banana location fields in Madeira would add great value to improve plant productivity on the whole Island.

Acknowledgements

The authors would like to thank the invaluable collaboration of:

- Gonçalo Machado, Iúri Viveiros, Pedro Carvalho, and Fausto Carvalho, from Altice Labs.
- Helena Garcês, Francisco Silva, Rúben Sousa, Rui Gouveia, Jorge Dias, and Artur Lima, from GESBA-Empresa de Gestão do Sector da Banana, Lda.
- João Neto, Pedro Sousa, Gregório Freitas, Carla Gouveia, from ISOPlexis Centre Sustainable Agriculture and Food Technology – Madeira University.
- Fábio Mendonça, Sheikh Mostafa, Ahatsham Hayat, Preety Baglat, from Interactive Technologies Institute / Larsys and Universidade da Madeira.
- Carlos Gomes , from ARDITI - Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação.
- Pedro Abreu, Filipe Freitas, and Jorge Sequeira, from Altice Portugal.

Fundings

- LARSyS (Project- UIDB/50009/2020), and M1420-01-0247-FEDER-000033.
- Project BASE: BAnana SEnsing (PRODERAM20-16.2.2-FEADER-1810).
- ARDITI – Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação under the scope of the project M1420-09-5369- FSE-000002 – Post-Doctoral Fellowship, co-financed by the Madeira 14-20 Program - European Social Fund.

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DOI: https://10.57650/innovaction/2022.11

11

Can we escape the Metaverse? Should we?

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In view of the strong market presence and leverage of major corporations involved in this topic, the most straightforward answer to the questions above is 'No'. Nevertheless, multiple perspectives should be considered. Thus, in this article we reflect on the concept of 'metaverse', what parts of it exist today, and what is foreseen that makes this concept a much-discussed game changer.

Keywords

Metaverse; Human-machine interaction; AR; Immersive virtual reality

How did we get here?

The term 'metaverse' has been around for quite some time, despite becoming a hot buzzword recently. It was created by Neal Stephenson in his 1992 novel Snow Crash [1]: *"So Hiro's not actually here at all. He's in a computer-generated universe that his computer is drawing onto his goggles and pumping into his earphones. In the lingo, this imaginary place is known as the Metaverse."*

In Stephenson's vision, the Metaverse was not a concept, but a specific virtual place, one contiguous virtual world. It did not stop there, though: he also stated that his protagonists were interacting with others as virtual bodies, being thus bodily present in that virtual world (as opposed to viewing it but not being part of it, the 'cyberspace' perspective which was a more common perspective at the time): *"He is not seeing real people, of course. This is all a part of the moving illustration drawn by his computer according to specifications coming down the fiber-optic cable. The people are pieces of software called avatars. They are the audiovisual bodies that people use to communicate with each other in the Metaverse."*

This concept of virtual worlds populated by embodied avatars had predated Stephenson. Depending on how we organize the history of this field, we are now probably in its fourth [2] or sixth [3] era of development and excitement. They originated in the late 1970s and early 1980s, leveraging prior text-based single-player 'adventure' games, where environments were described rather than shown. As in those single-player adventures, in the first multiplayer system, 'Multi-User Dungeon' (MUD), the participants were indeed inside: they would move around, pick objects, and fight, all via text descriptions and typed commands [3]. Inspired by MUD, many systems emerged, and, eventually in 1985, a first graphical multi-user world that employed the term 'avatar' for the embodied participants, Lucasfilm's Habitat [4], albeit short-lived. The 1990s saw such systems leverage the higher number of participants enabled by the internet, rather than by dial-in telephony systems, originating the still-used term MMORPG, for massively multiplayer online role-playing game, such as Ultima Online's 100 000 paying players [2][3].

FIGURE 1 – SLACTIONS 2009 virtual conference in Second Life

The MMORPG enthusiasm blended with the proposal of non-gaming social worlds, emerging in the early 2000s, such as Active Worlds [5], IMVU [6], and, indeed, the media sensation of the late 2000s, Second Life [7]. It was during this era that the term 'metaverse' started to emerge again, with each individual virtual world being designated as 'a metaverse', and popular culture embracing the concept of vast, immersive worlds for entertainment, socializing, education, events, and more. As an example, **Figure 1** was taken during an academic conference held in Second Life in 2009. Common examples in other areas of popular culture are science fiction movies such as 1999's The Matrix [8] and books such as 2011's Ready Player One [9]. This was the computing and cultural panorama influential to Google, Amazon, and Facebook founders, among others.

What is the Metaverse today?

At some point in the early 21st century, the view of 'metaverse' as a synonym with individual virtual worlds changed. Our world - our existence, was increasingly being understood as a blend of physical and virtual elements, given the quasi-omnipresence of the internet. And so, the concept emerged of the Metaverse, instead of multiple, isolated metaverses: “*interconnection between virtual worlds that could lift them from the BBS age into the web age*” [10]. Envisioning the existence of a “*post-reality universe, a perpetual and persistent multi-user environment merging physical reality with digital virtuality*” [11].

Such a transformative perspective on how and where people interact naturally led to intense interest from the tech giants, each attempting to be at least part of the core technology that supports this vision. Microsoft announced its metaverse strategy at the Build 2022 conference [12], and Facebook changed its own corporate name to Meta the year before with this rationale [13]: “*(...) an embodied internet where you're in the experience, not just looking at it. We call this the metaverse (...). The metaverse will not be created by one company. It will be built by creators and developers making new experiences and digital items that are interoperable and unlock a massively larger creative economy than the one constrained by today's platforms and their policies.*”

However, the tech giants are arriving on a scene brimming with new, innovative players who have mastered the development of user communities, platforms, interaction, and dynamics. These include Fortnite from Epic Games, with initiatives such as the recent MetaHuman Creator [14], Minecraft (acquired by Microsoft in 2014), and Roblox, which enable children to create innumerable and vast interactive worlds [15]. The immersive virtual reality experience with headsets such as Facebook's (i.e., Meta's) own Oculus or others is abuzz with companies such as Rec Room, AltSpaceVR (acquired by Microsoft in 2017), VRChat, and more [16].

The technology

“*Designed for gamers, by gamers, to take 3D gaming to the next level*”, Oculus Rift crowdfunding in 2012 boosted the virtual reality (VR) scene deeply. With over 9500 backers, it raised almost 2.5 million USD, a factor of 1000 to the original Kickstarter campaign goal [17]. Despite the motion sickness problem, immersive VR games skyrocketed in popularity, with headsets reaching the affordable price range of USD $300 for the few buyers who managed to acquire them (**Figure 2**).

FIGURE 2 – Oculus Rift development kit v1 (2012) (source: virtuall.hu)

There are now, in the stead of Oculus Rift, several high-quality devices available in the market, such as Sony PlayStation VR, Valve Index, HP Reverb G2, and HTC Vive Pro 2, among others. As for the emblematic Oculus headset, the company was acquired by Meta/Facebook in 2014, and the current version of the headset is the Meta Quest 2 (formerly Oculus Quest 2). It remains

FIGURE 3 – Left: VR-OBT - virtual reality on-board training (2022) (source: European Space Agency); Right: Oculus Quest 2 guardian boundary breaching situation (source: arvrtips.com)

the benchmark for comparison with others, with features that include the freedom of a truly wireless untethered experience, high-resolution video, broad field of view, smooth motion tracking, finger-tracking controllers, high refresh rates, and low latency to avoid nausea (a.k.a. motion sickness).

The availability of this class of technology has been fueling countless applications for education and training, using powerful role-playing scenarios and taking advantage of the easy exploration of interactive 3D content and models, even when orbiting Earth (**Figure 3, left**). Particularly relevant is the guardian boundary features (**Figure 3, right**), which display a grid to the user if the arms or body extend beyond a previously-defined safe area without obstacles. Should the user step outside of it, the outside cameras of the headset dismiss the virtual world and present the physical world image to the user to avoid accidents.

Mixing holographic or virtual content with live video and augmenting reality are key requirements for many interesting professional use cases. The technology for building affordable and comfortable mixed reality (MR) headsets or glasses has been more challenging and evolved slower than VR, but it's finally catching up. Microsoft Hololens 2 is currently the MR market reference headset, albeit expensive, with Magic Leap One and Nreal Air glasses (**Figure 4**) emerging as attractive, light, and simpler devices, tethered to a mini PC that almost look like regular sunglasses.

FIGURE 4 – Nreal Air glasses (2022) (source: Nreal)

As hinted above, current metaverse platforms are mostly proprietary and non-interoperable. So, creating a particular scenario, e.g., hosting a virtual conference, typically requires custom content development and 3D building on top of whatever resources and templates are made available by the service provider. This situation is improving somewhat by emerging standards for 3D models, but there are no widespread ways to do the same for automated interactions. Consequently, users can't reuse assets across environments, e.g., the same embodied avatar that represents them. Frame VR [18] is a recent collaborative virtual reality platform by Virbela, mitigating complexity by providing a simple and customizable immersive online meeting space that works right from the web browser, including simple presentation-style creation tools, without the need to download or install anything, accessible with most VR headsets or even with a mobile device.

What's next?

It's commonplace to acknowledge that we are still in the early stages of the adoption of metaverse technologies, and fragmentation is one typical major hurdle facing widespread adoption [19]. Still, the technology has moved beyond proof-of-concept and has the stability, ease of use, and price range to enable it: the stand-alone Oculus Quest 2 is available in Portugal with 128GB storage for €457, with the 256GB version available from €559 (KuantoKusta.com, Sep 25, 2022). These are price points around the overall context of gaming consoles for comparison: Sony PlayStation 5 825GB at €799, Microsoft Xbox 1TB at €489, and Nintendo Switch 32GB at €259.

In the enterprise and educational worlds, 3D virtual collaboration is in its infancy, as shown above. Recent studies reinforce social aspects of being online together, which helps explain the effectiveness of communication and people interaction in virtual immersive settings [20], something that regular users quickly experience. The COVID-19 pandemic made further evidence of this, and we have seen important moves in the tech giants world, pushing new formats of remote teamwork, with Meta introducing Horizon Workrooms and Microsoft adding Mesh mixed reality communication to Teams collaborative platform (**Figure 5**), with hundreds of millions of users.

The anticipated rise in the professional use of immersive collaborative platforms, along with the 3D gaming habits of the younger (and not-so-young) generations, will expose a growing audience to VR and MR, getting relatives and friends acquainted with technology and eager to give it a try. Immersive social networking and entertainment will thrive in light of this multiplicative effect, further boosted as the hardware prices fall and the applications improve.

In the coming years, metaverse scope is likely to be enhanced by technological confluence, e.g., artificial intelligence (AI) empowering persistent personal assistants and content creation, multisensorial devices bringing deeper immersion, 5G mobility enabling MR massive experiences, distributed ledger technology (DLT) and non-fungible token (NFT) allowing new business models and supporting novel art and media formats. It will be a vibrant ecosystem of innovative digital platforms teeming with new opportunities, new skills, and new jobs. The European Union is aiming for a strong position

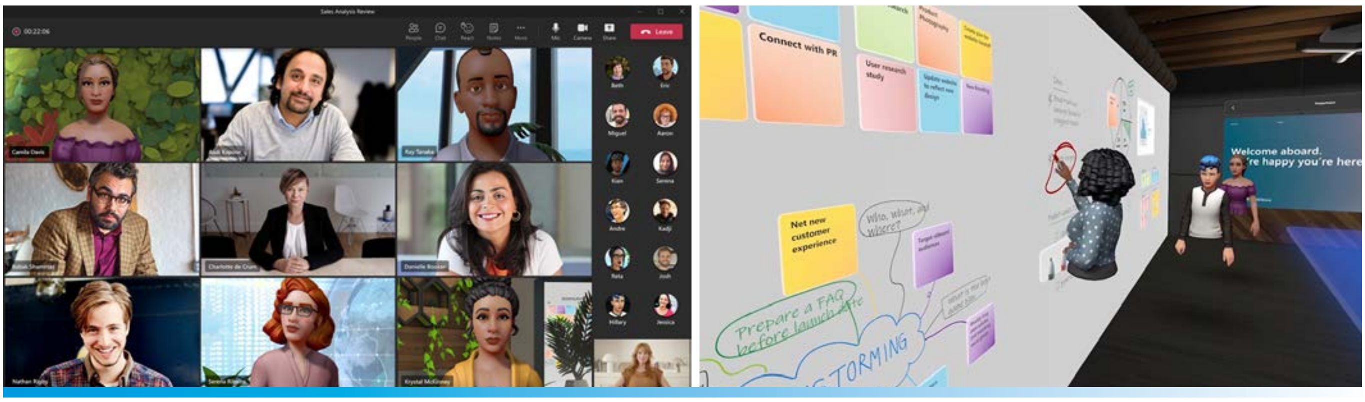

FIGURE 5 – Microsoft Mesh for Teams (2022) (source: Microsoft)

and brought together stakeholders from key metaverse technologies into the Virtual and Augmented Reality Industrial Coalition [21].

Currently, there is a huge buzz and many ideas flowing around metaverse topics. Each major player seems to be attempting to fit their current services, technology or portfolios into exploitation roadmaps, bending definitions of what the Metaverse actually is and will be in the future. The bottom line is that none of them is completely right or wrong: it's very likely that the Metaverse will be a bit of all those disjoint visions, and many use cases being discussed make sense and will certainly have a significant impact in the market, either for good or less favorable reasons.

There are some good teasers of what might be upcoming in the metaverse domain, which should probably be carefully watched by anyone willing to grasp a good insight on these questions, in the same spirit that the book 'Snow Crash' was at some point required reading for Facebook's management team.

The immense success of the science fiction movie 'Ready Player One' directed by Steven Spielberg (2018) [22], based on the aforementioned Ernest Cline's novel of the same name [9], which itself can be described as a novel inspired by the Second Life virtual world [23], recently provided new cultural fuel to the vision of near-future enmeshed with a virtual reality universe used by almost everyone to escape from their dystopian reality into a massive multiplayer video game, and explores several technological and social key aspects of a fully immersive metaverse.

Moving away from complete isolation and escapism to alternate totalitarian virtual realities, Niantic, among other companies, sees the Metaverse as a powerful and versatile way to augment reality with virtual content through the use of augmented reality devices. The company behind successful games such as Ingress [24], Pokémon Go, and Harry Potter's Wizards Unite, made recently available the Lightship platform, which allows the management of dynamic content overlays onto the real world, allowing millions of people to have a consistent, simultaneous, synchronized and shared interaction experience with digital objects in the physical world [25]. Liquid City is partnering with Niantic and prepared the interactive installation 'Reality Channels' (**Figure 6**), demonstrating a future vision for this Real-World Metaverse at Niantic's developer conference, the Lightship Summit 2022 [26].

FIGURE 6 – Reality Channels prototype @Lightship Summit 2022 [26]

Closing remarks

It's not foreseeable, and in fact, it is much undesirable, that at some point we will become like Snow Crash gargoyles, individuals that "*wear their computers on their bodies (...) serve as human surveillance devices, recording everything that happens around them*" [1]. Yet, we are more often than not permanently connected, always on, living and working in a fully immersive experience, blending our physical surroundings with the virtual elements that arrive via the device-rich environment of our lives. The Metaverse will certainly bring many game-changing aspects of human-machine interaction to our day-by-day digital way of life. In the forthcoming years, mobile extended reality (XR), powered by 5G, edge computing, AI, and comfortable augmented reality glasses or contact lenses, will steadily make room for more and more powerful applications and sophisticated metaverse scenarios, bringing more magic into the thin and breathtaking borderline between reality and science fiction.

So, we can't escape the Metaverse, whatever it will be, unless we escape human society itself. As to whether we should, the answer is philosophical as much as political, but must be answered in this entangled context: the Metaverse will be enmeshed with society, and decisions about one will be decisions about the other.

"*Any sufficiently advanced technology is indistinguishable from magic.*" Arthur C. Clarke

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DATA FLOW
46
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BODY TEMP
TIMER
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MAIN SCREEN
Xray
Grid
Press button

DOI: https://10.57650/innovaction/2022.12

12

Digital health: current trends and applications on innovative care

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Digital health is a strategic approach to meet the need to provide health care to an increasingly aging and often isolated population and those who need continued care without needing to be institutionalized (e.g., chronic patients). Digital technologies can shape the future of global health, having great potential to accelerate human progress and develop knowledge societies, transforming and optimizing healthcare.
As a part of this vision, this article will present two products from Altice Labs portfolio: Medigraf and SmartAL.

Keywords

Healthcare; E-health; Digital health; Medigraf; SmartAL

Introduction

Traditional healthcare is moving towards a new scenario of digitally connected care ecosystems. A driving force is emerging that can help move from reactive to proactive strategies, improving patient interaction and transforming the digital sector [1]. Digital solutions have the power to address current health challenges, namely, an increasingly aging population, the enlarged prevalence of chronic diseases, the shortage of health professionals, and the remaining disparities in access to health services.

Digital technologies can shape the future of global health, having great potential to accelerate human progress and develop knowledge societies. An innovative health ecosystem is being shaped, creating a continuum of care that surpasses the traditional time and space barriers. It's a new scenario that also faces challenges, as the developed solutions must be guided by ethical, safe, secure, reliable, equitable, and sustainable principles. Transparency, accessibility, scalability, replicability, interoperability, privacy, security, and confidentiality are also imperative guiding points [2].

Several trends, like remote monitoring applied to different levels (diagnosis, consultation, and surgical), internet of things (IoT) devices, data analytics, and artificial intelligence (AI), can leverage a new paradigm of preventive medicine and help to reduce pressure and costs on healthcare systems.

Recently the World Health Organization (WHO) launched a first step towards the definition of an action plan for 2023-2030 considering digital health in Europe [3].

Topics like equity, solidarity, and human rights are transversal to the proposed strategy, which is anchored in four strategic priorities: (i) setting norms and developing technical guidance; (ii) enhancing country capacities to better govern digital transformation in the health sector and advance digital health literacy; (iii) building networks and promoting dialogue and knowledge exchange; and (iv) conducting horizon-scanning and landscape analysis for patient-centered solutions that can be scaled up.

Among other dimensions, the WHO identifies international cooperation as a critical issue, underlining the importance of platforms like the e-health Network [4]. **Figure 1** depicts the five guiding principles that are presented to support the sustainable adoption of digital health [3]:

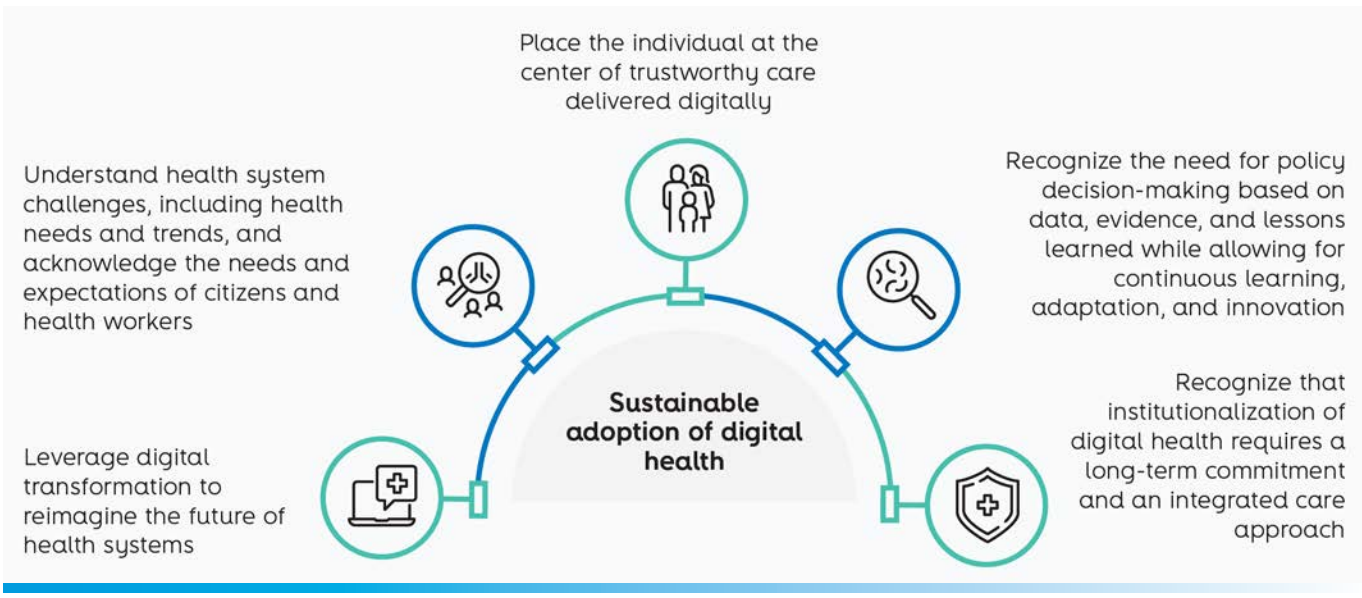

FIGURE 1 – Guiding principles to support the sustainable adoption of digital health

Critical health scenarios

As portrayed during the last years, health emergency situations are increasingly prevalent. The COVID-19 pandemic created a unique scenario, speeding up digital transformation and creating new opportunities to reconfigure both patient and health professionals' digital experiences. Now it is time to scale out both the innovative digital care delivery models already in place before the pandemic and the new ones brought up in the last two years, enabling the consolidation of more consistent integrated care models.

Different benefits of this recent transformation have been consensually described [5]: breakdown of geographical and time barriers, reduction of waiting lists and crowding in healthcare facilities, and saving on national healthcare budgets. However, despite those positive effects, bureaucratic and regulatory issues remain as potential barriers, as well as users' skills and attitudes (like patients' literacy or health professionals' commitment). The COVID-19 pandemic underlined how critical it is to: strengthen the resilience of health systems; pay special attention to vulnerable populations; analyze the impact of isolation on mental health; better listen to end-users and develop person-based approaches [6].

The pandemic reinforced the idea that digital health can help to better understand and reduce disparities, while conventional channels failed to respond to current needs. Digital health solutions proved to be able to orchestrate resources to improve health equity [7].

Notwithstanding this equalitarian view, policies and strategies must be designed carefully. Despite the benefits that digital health brings to both patients and professionals, it may also stress inequalities regarding accessing health care services. Therefore, health literacy should be carefully considered to avoid deepening existing health inequalities and better promote patients' readiness to adopt digital health solutions [8]. The lack of digital literacy is a big challenge when developing easy-to-use digital solutions.

Surgical care in vulnerable sites

Vulnerable sites (e.g., remote areas, developing countries, military settings, or emergencies) can benefit from virtual and augmented technologies, which can extend real-time collaboration between experts, namely in the fields of surgery and radiology. Besides training and support for less qualified health professionals and streamlining resources, these solutions can also reduce long-distance travel for surgeons and radiologists. Altice's long-standing experience in regularly providing teleconsultation services (offered by Medigraf [9]), connecting specialized hospitals in Portugal to other institutions located in countries like Cape Verde and Angola, has been possible due to the availability of reliable connectivity.

The existence of a robust infrastructure, especially during global health emergencies and in the face of real-time requirements, is a primary condition: the ubiquitous adoption of 5G technology (ensuring low latency, high reliability, and high bandwidth) is of great importance, considering scenarios where robotic surgery, immersive virtual simulations, where haptic feedback and virtual control of critical medical procedures demand high connectivity for effective operation.

Rescue scenarios

For remote monitoring and evaluation in critical scenarios, solutions like the ones enabled by drones can be a gateway to increase the quality of healthcare services. Despite some current challenges related to safety and security and the involvement of local authorities, important results have already been described when using drones to support innovative healthcare approaches [10].

When associated with 5G networks, drones can be part of an innovative health approach to support critical communications scenarios: complementary monitoring solutions provided by rescue teams can

FIGURE 2 – PPDR simulacrum (Aveiro 2019)

communicate with drones, while these can enable the aerial observation of an accident scenario and facilitate real-time rescue operation. This is particularly relevant when considering public protection and disaster recovery situations.

Altice Labs has already set up demo scenarios associating teleconsultation, monitoring, and aerial observation via a 5G infrastructure to show its potential. In September 2019, Altice Labs conducted a public protection and disaster relief (PPDR) simulacrum to demonstrate the potential of 5G technologies, involving the Aveiro City Council, the local Civil Protection Authority, the Public Security Police, the Baixo-Vouga Hospital Center, the Military Health Center of Coimbra and the two Aveiro volunteer fire corporations. Rescue teams – security, fire brigade, and emergency medical teams – were mobilized to provide aid to a driver involved in a simulated car accident. A drone was used to scan

the area and collect information about the tactical means necessary for the firefighter to carry, and sensing vests were used to monitor the vitals of the firefighters and police officers involved. Also, teleconsultation services were in place between the ambulance and the hospital to ensure the best healthcare assistance possible (as depicted in **Figure 2**). This year, a similar exercise took place in Funchal, in Madeira, using the commercial 5G network from Altice, with remarkable success.
The use of 5G-enabled healthcare applications in emergency situations, especially in difficult access places like ravines, is extremely important for local authorities. Also, this year, a real-time streaming operation using virtual reality devices took place at the Champalimaud Foundation, in Lisbon, and was visualized remotely, in Aveiro, via 5G. These are just some interesting scenarios where technology is a major triggering factor.

Emergent technologies

Big data, analytics, and AI

Big data and analytics in healthcare allow better collection and analysis of patient data, enriching prevention, monitoring, diagnosing, demand management, and fostering innovation and research. Contributing to the digital health scientific domain requires the implementation of open, secure, and robust policies regarding health data. For example, big data processing is of paramount importance in the epidemiologic field, as it can give epidemiologists a better understanding of diseases' evolution and allows them to prevent worst-case scenarios or at least anticipate actions and mitigate their consequences.

When looking at the services level, an integrated and interoperable approach to health data is needed. For instance, an application to be used by patients with respiratory problems needs to interoperate smoothly with environmental data on pollution [11], and apps designed for people with diabetes must be integrated with real-time glucose monitoring devices. Data is currently being collected from innumerous types of sources, like clinical devices, wearables, questionnaires, exams, images, etc.; the challenge, however, is to guarantee that it is 'good quality data'. Analytics and machine learning (ML) algorithms do not run well on poor-quality data, meaning on non-reliable or less meaningful data. In this case, inferences, conclusions, and recommendations may lead to results with potentially dangerous consequences for the patient.

AI has also been described as a potential tool to improve e-health literacy and combat misinformation/disinformation phenomena (such as the COVID-19 infodemic): AI-augmented lifelong learning, AI-assisted translation, simplification, and summarization, and AI-based content filtering are currently important fields of innovation [12].

Cross-wising these benefits, security challenges must be kept in mind, as confidentiality and data privacy will always have to be protected.

In collaboration with external entities and universities, Altice Labs is currently working on the analysis and development of ML algorithms to support the diagnosis and give recommendations to patients suffering from retinopathy, an eye condition that can cause vision loss and blindness (often a complication of diabetes) and chronic diseases, as hypertension and diabetes.

Ambient sensing and connected technologies

Digital technologies can support healthcare providers to better deliver care at home. In this area, the COVID-19 pandemic also revealed new opportunities to accelerate the creation of new models of hospital-at-home care and prevention and follow-up.

Wearable biosensors have an important role in collecting and monitoring a wide range of physiological parameters that, when combined with other data (for example, electronic health records, EHR), can support clinical decisions, expanding care beyond hospital walls. It's a new approach that can improve outcomes, reduce costs, and offer more convenient care, namely for minor illnesses, recovery stages, age ailments, chronic diseases, etc. Besides physiological data, psychological, social, and environmental parameters can also be collected, extending the patient monitoring to other complementary layers, such as the emotional one.

Ambient sensing and connected technologies have great potential, for example, assistive healthcare robots. But despite having shown early promise, they revealed some fragilities as their value did not prove to be able to support their costs [13]. Nevertheless, Altice Labs has adapted its telemonitoring application SmartAL [14] to one of these robots [15] as part of its job to create new and inventive solutions running on different devices and interfaces to serve different types of people. Robots seem to have great potential as quick healthcare enablers to help elderly patients or, generically, people with limited mobility in their daily life. Simple things, such as watching a video or answering a questionnaire, can be performed via a robot interface. Also, tasks scheduled by health care professionals using the SmartAL web interface or the mobile app may be presented to the patient in a friendly way. For example, when the time comes, the robot may talk to the user using an encouraging sentence and remind him or her to stand up and walk slowly for the next ten minutes, or say "*Please take your medication. It is not a big deal, just takes 1 second!*". The robot can also ask the user to measure the blood pressure at specific moments since it has a Bluetooth interface that allows automatically collecting vitals from several clinical devices. Furthermore, it responds to voice actions, is capable of face recognition, and maps indoor locations after a pre-learning scanning process. So, it may become handy to send it to some predefined locations (e.g., living room, sleeping room) and ask it to collect a box of pills or scan the entire house looking for an informal caregiver to hand over a thermometer to perform a daily measurement.

Despite some still prevalent barriers regarding users' privacy, security, and policy issues, ambient sensing and connected technologies can also ensure the surveillance of residential users. Behavioral analytics can be used through unobtrusive monitoring and real-time situational data, promoting patient safety and detecting abnormal behaviors [13]. The IoT paradigm leveraged important trends, namely the ones related to assisted-living environments and smart homes, supporting vulnerable residents to live longer independently in their own homes [16].

In this context, the SmartHome [17] solution developed by Altice Labs is tailored to control the environment in the house (e.g., lights, plugs, heating) and ensure security (e.g., motion, fall and opening/closing doors and windows detection), but it can also provide precious complementary information to the SmartAL assisted living ecosystem, since all this IoT data may be used to learn more about the habits and routines of the residents and infer anomalous and risky situations, in terms of the state of health and well-being.

Besides IoT, mobile and wearable technologies (e.g., smartwatches and smartbands) are increasingly being used to collect physiological, contextual, and environmental measurements. Also, low-intrusive technologies such as contactless devices (e.g., contactless portable respiratory rate monitors, thermometers), wearable sensing solutions (e.g., flexible sensors and electronics, textile sensors, etc.), technology integrable into daily objects (e.g., capacitive sensing integrated into chairs), and implantable devices are being used to collect data. On top of this, AI and predictive analytics can translate data into knowledge, providing real-time insights valuable to make better-informed decisions and automate and streamline work processes to reduce the burden of providing care in accordance with every patient situation. Using these approaches, patients can be monitored completely transparently with reduced intrusiveness.

As for teleconsultations, these can have the potential for non-emergency care, symptom triage, and improving access to healthcare services for those with mobility challenges. It is a scenario that can reduce the number of unnecessary trips to emergency rooms and be a part of the patient's care continuum, including prevention and follow-up. This is particularly relevant for patients with chronic conditions [13]. Assessing the condition of patients before face-to-face consultations is a significant benefit, enabling the monitoring of at-risk patients.

This partnership between empowered patients-at-home and physicians is creating new scenarios of participatory health, in which patients are true partners of the process, being of utmost importance to include them in the design of healthcare models [18].

As a part of this vision, Altice Labs developed two products already mentioned in this article, Medigraf, and SmartAL.

Altice Labs' e-health solutions

Medigraf

Medigraf [9] is a teleconsultation and clinical data-sharing solution that allows healthcare professionals to work together remotely on a given clinical case. It offers a collaborative web environment over internet access to conduct medical appointments using audio and video conferencing tools. During the conference, it is possible to share real-time streaming information coming from medical devices (e.g., ultrasound images) as well as medical imaging information and data (digital imaging and communications in medicine, DICOM) or simple files (e.g., photos/images or analysis/pdf).

In 1998, the strategic purpose of developing this tool was to bridge the lack of specialized healthcare professionals in remote areas and offer patients better diagnoses and treatments. Also, it was important to bring more comfort and reduce costs from the constant travels of patients from peripheral regions to central hospitals (where the medical specialists are usually located) and medical specialists that need to assist other professionals on more complex cases. To fulfill this gap, Medigraf allows healthcare professionals to work remotely as a team, regardless of the distance between them. Over the years, this platform has become an everyday tool for healthcare institutions, responding efficiently to the needs of physicians, favoring collaboration, and enabling the implementation of a new paradigm of communication and cooperation. Besides regular teleconsultations between healthcare professionals in different institutions, Medigraf also allows to schedule and perform teleconsultation appointments directly with the patients, which proved to be an extremely important feature during the pandemic (**Figure 3**).

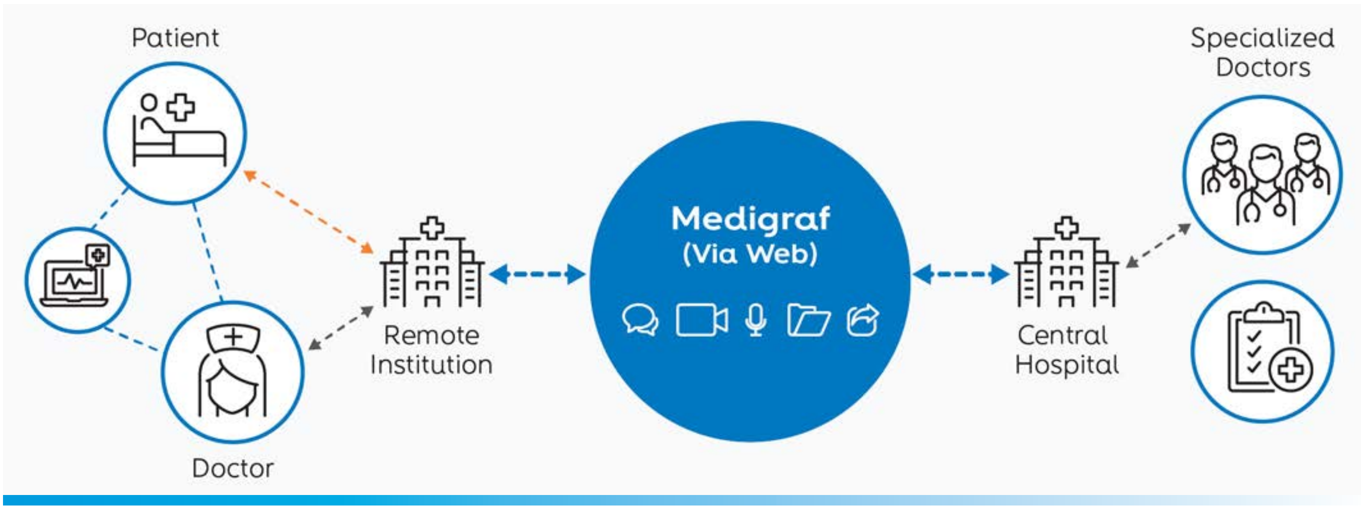

FIGURE 3 – Medigraf: teleconsultation doctor-doctor and doctor-patient

Currently, the Medigraf solution is the key supporting tool of a regular teleconsultation service between specialists at the Central Coimbra Hospital (Centro Hospitalar e Universitário de Coimbra - CHUC) and doctors in remote hospitals from Portugal's central and northern regions. Moreover, it provides a similar service to hospitals in Portuguese-speaking African countries, like Angola and Cape Verde, and private institutions of public utility, as in the case of Instituto Marquês Vale Flor (IMVF) [19] in several medical specialties. This institute plays a very important role in medical cooperation with São Tomé and Principe and other Portuguese-speaking countries.

SmartAL

SmartAL [14] is a technological ecosystem that aims to simplify people's daily lives from both a clinical and social point of view. It was designed as a flexible solution to meet various assisted living use cases, from seniors to children, from care for chronic diseases to home care, and from social prevention to clinical follow-up of people in a state of fragility or isolation. This tool helps people with their daily care needs, as well as their families, professionals, and health/social care organizations.

SmartAL is a telemonitoring and teleconsultation tool where end-users (patients, family members, and caregivers) may follow in real time the health status of the patients while other ecosystem participants may assist with several complementary actions (**Figure 4**).

The core functionality of this tool consists of collecting information from clinical (e.g., oximeter) and non-clinical devices (e.g., personal band) and making it available to both patients and caregivers to have an overview of the patients' vital signs (**Figure 5**). The collected data is compared with the thresholds previously set by

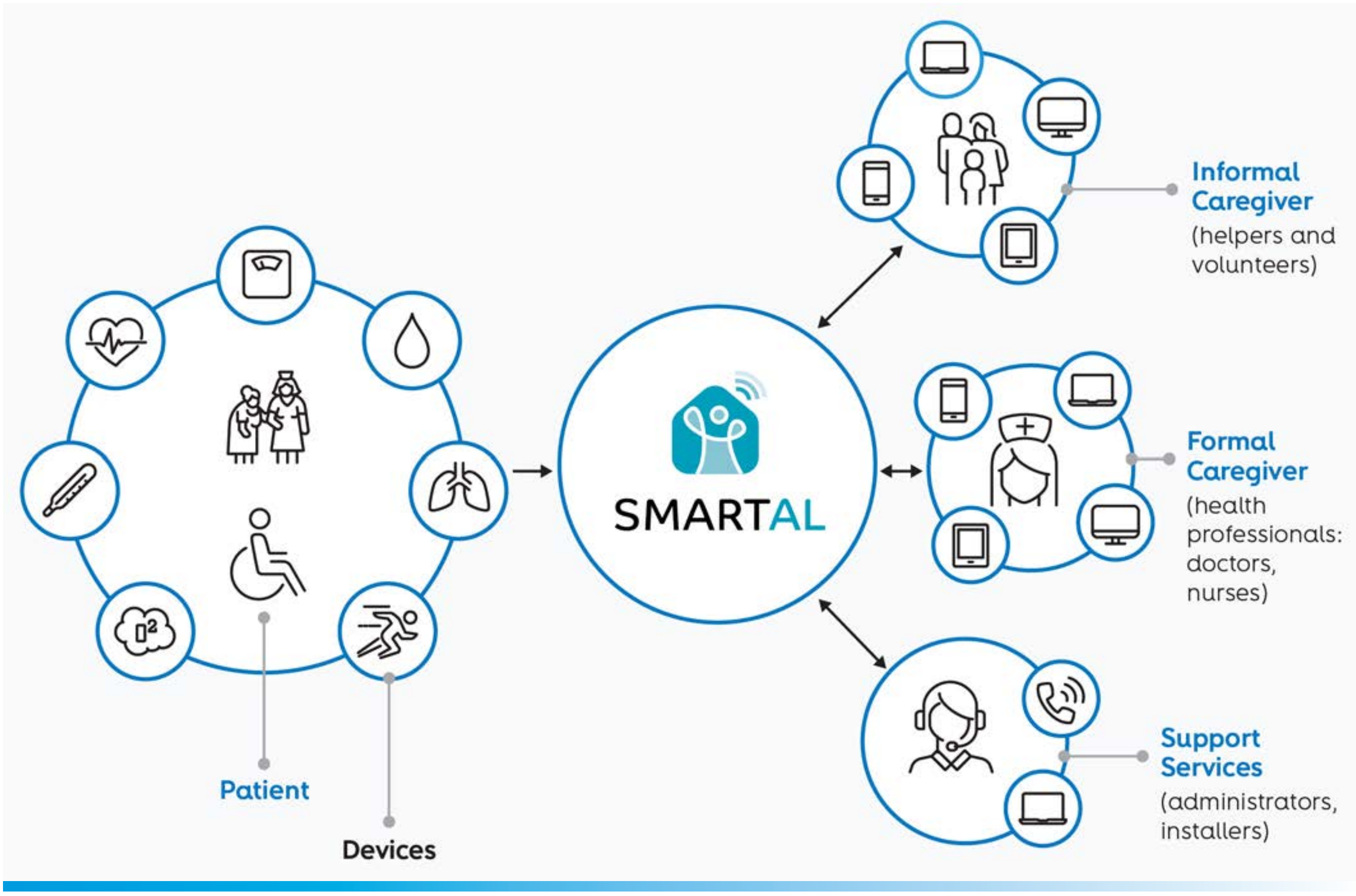

FIGURE 4 – SmartAL ecosystem

FIGURE 5 – SmartAL clinical and non-clinical devices (wearables)

health professionals, and if values are outside the limits, notifications are immediately sent so that actions can be taken (e.g., schedule a teleconsultation).

From the patients' perspective, the key concept that guides and sustains their daily activities are tasks and plans (groups of tasks); tasks are usually scheduled by caregivers to keep track of the users' daily duties and to remind them when to perform them. There are predefined types of tasks, such as collecting clinical measurements, taking medication, and participating in teleconsultations, but also a free type allowing professionals to add new activities on the fly (e.g., take a five-minute walk, drink a glass of water every day). A task may be assigned to one or more patients and configured by defining the time interval in which it should be executed and who should be notified in case the task is or is not executed.

In addition to telemonitoring and teleconsulting, SmartAL also allows for the inclusion of simple questionnaires to assess the general state of well-being of the patient, and videos, to help him or her in the use of clinical equipment, how to deal with his/her illness or give incentives and recommendations about nutrition and other healthy habits.

SmartAL is based on different services and technologies, aiming to serve everyone in the friendliest way possible. It is multilingual and supports multiple user interfaces so that it can be adapted to the needs of each customer (see **Figure 6** on the next page). It can be accessed via smartphone, tablet, PC/web browser, or TV (as an interactive IPTV mediaroom application or on Android TV). The caregiver/professional can access a complete front office via PC or tablet. The platform provides all the configured services and manages the scheduling of each user, generating automatic alerts and notifications that can be sent to both end-users and caregivers on multiple interfaces. SmartAL allows end-users to achieve a high degree of independence, autonomy, and dignity, feeling safe both inside and outside the home, as they have a friendly tool that helps them manage their daily lives and prevent risky situations.

In summary, SmartAL is capable of serving multiple target audiences with various benefits to both end-users and professionals, while it is foreseen to have a stronger impact on several clinical and social aspects, such as: extending the time people can live in their preferred environment by increasing their autonomy, self-confidence, and mobility; supporting the maintenance of health and functional capabilities of end-users, namely old adults; promoting a better and healthier lifestyle for individuals at risk; improving 'always-on' interaction between each person and his social ecosystem, especially with

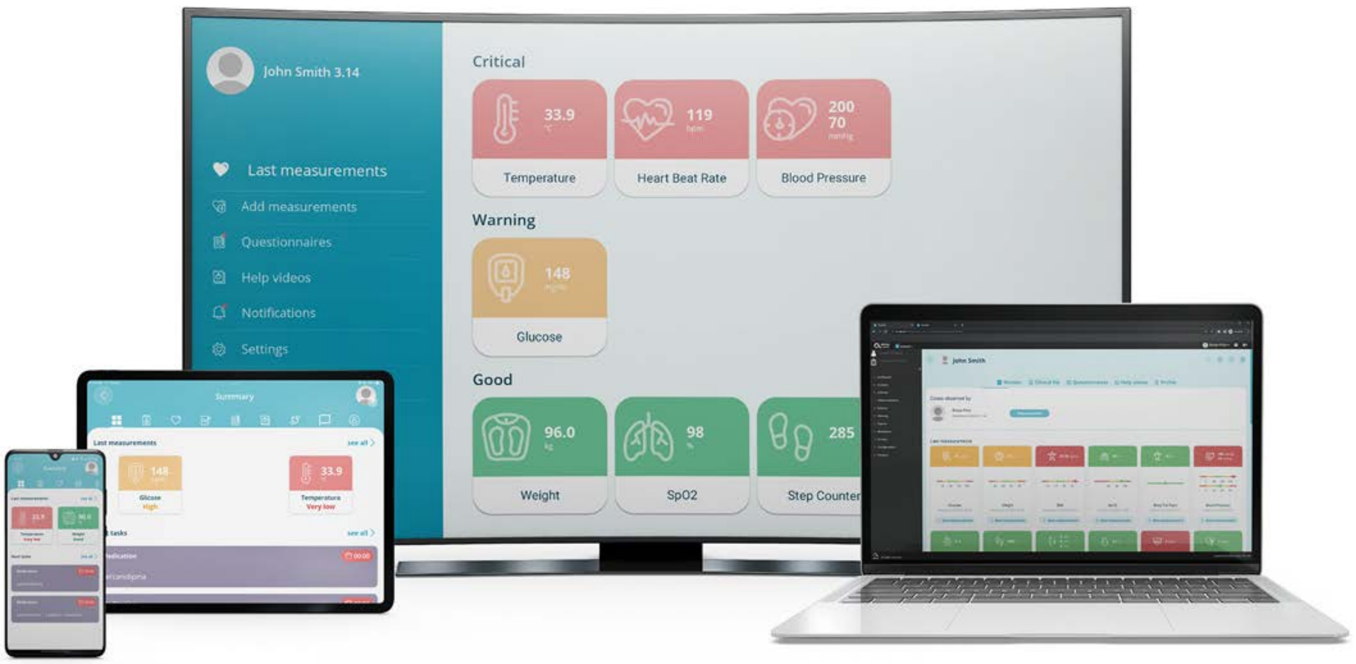

FIGURE 6 – SmartAL user interfaces

their caregivers, preventing social isolation and increasing their feeling of personal security; and finally, stimulating the growth of supported clients (more revenues), for individual professionals and institutions.

Valuing person-centric health experiences

Digital tools can empower a person-centered healthcare approach. Current trends show the importance of creating positive end-user experiences when designing digital health services. Easiness, comfort, and scalability are critical issues when designing health interfaces enabling:

- For the end-users, an immediate sense of the product value and available features, reduced screen time, and low-level skills to understand how to interact with systems.
- For the development teams, no need to add new layers of complexity each time a new product/service is presented, supporting the rapid deployment of new applications.

Such a strategy can help to scale up new solutions, deliver better user experiences adapted to all, and ensure patient engagement and loyalty. This new approach can leverage people-care and value-based care strategies.

For those in vulnerable situations, it is even more important to develop community-based participatory approaches, namely when researching user needs to inform interface design. Differentiating life situations, motivations, and e-health expectations is the basis for developing digital health solutions adjusted to end-users' daily life [20].

Person-centric healthcare delivery models underline the importance of looking at digital engagement as a driving force for the enhancement of patient experiences. It is necessary to deepen attention to the development of solutions that can leverage the creation of trusted digital relationships and prioritize access to empathic, comfortable digital experiences [21]. Poor user-centered design can lead to low digital adoption [13].

Health professionals are also first-level beneficiaries of a more enriched and person-centric approach to interface design. Among other reasons, health professionals' burnout has been described as caused by EHR poor usability. A well-designed interface can reduce the time and effort of using EHR. This is particularly relevant considering clinical data's growing complexity and volume [13].

In this context and as part of its evolution strategy, SmartAL is being restructured following, on the one hand, new usability guidelines and accessibility principles, and on the other, standards [22][23] to shape a new EHR able to store all the relevant patient data and ensure communication with other health care systems and databases. Also, engagement and gaming techniques (some involving virtual reality) are being developed and incorporated into the application as incentives to the users. Games will be considered in different contexts, such as cognitive training, physical exercising, physiotherapy, entertainment, and socialization, since it is proven to be also a determining factor in recovery.

Conclusions

Digital health is a strategic approach to meet the need to provide health care to an increasingly aging and often isolated population and those who need continued care without needing to be institutionalized (e.g., chronic patients). Technology can accelerate care delivery in these cases, transforming and optimizing healthcare.

Despite the recent developments described, data, interoperability, trust, credibility, and security challenges should be addressed at all stages of the development process. Each stakeholder involved in creating digital health solutions must be aware of the importance of consent, data ownership, privacy issues, and legislative compliance, namely with the European Union General Data Protection Regulation and Medical Device Certification. Working towards surpassing interoperability challenges is also necessary.

To retain the loyalty of consumers and support future developments, it is necessary to deepen knowledge of patient engagement strategies. To ensure such an approach, it is necessary to engage with early adopters and better scale-up pilots [13], advancing from trials to more sustainable development models.

It is also of most importance to establish strategic partnerships with diverse stakeholders, exploring, among others, opportunities in social responsibility with vulnerable populations. Use case diversification can be a path to enlarge the view on the broad spectrum of populations and scenarios that can benefit from the developments that digital health brought to the scientific community, the industry, and the market.

Further attention must be put in looking into evaluation and impact measures, namely through health technology assessment approaches [24]. These can be an instrument to provide evidence and determine the value of digital health solutions and inform guidance to support future innovations.

A continuous commitment to this evolution cycle is needed, creating sustainable and integrated strategies [25] able to be the catalyst for the improvement of technological, social, and human development, and in which the 'experience of care' is valued as one of the most important dimensions to support the design of innovative approaches in what concerns to digital healthcare.

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Acronyms & Terms

1	10G-PON	10 Gigabit PON
2	25GS-PON	25G Symmetric PON
	2D	Two-dimensional
3	3D	Three-dimensional
	3G, 4G, 5G, 6G	Third, fourth, fifth and sixth generation of mobile networks
	3GPP	Third Generation Partnership Project, a collaboration between groups of telecommunications standards associations
4	4P	Personalized, preventive, predictive, participatory
5	50G-PON	50 Gigabit PON
	5G-ACIA	5G Alliance for Connected Industries and Automation, a global forum for collaboration between automation, engineering, and process industries, and telecom operators and suppliers
A	AGITE	Altice Group IT Evolution
	AI	Artificial Intelligence
	Android	Mobile operating system developed by Google
	ANR	Automatic neighbor Relation
	API	Application Programming Interface
	AR	Augmented Reality
	ARDITI	Regional Agency for the Development of Research, Technology and Innovation
	AV	Audio/Video
B	B2B	Business-to-Business
	B2B2X	Business-to-Business-to-Business/Consumer
	B2C	Business-to-Consumer
	BBS	Bulletin Board System
	BC	Breast Cancer
	BEREC	Body of European Regulators for Electronic Communications
	BLE	Bluetooth Low Energy
	BSS	Business Support System
C	C2M	Concept-to-Market
	CAGR	Compound Annual Growth Rate
	CAPEX	Capital Expenditures
	CEx	Coexistence Element
	CHUC	Centro Hospitalar e Universitário de Coimbra (Central Coimbra Hospital)
	CO	Central Office
	CoC	Code of Conduct
	COTS	Commercial Off-The-Shelf
	COVID-19	Coronavirus disease 2019
	CPE	Customer Premises Equipment
	CSA	Connectivity Standards Alliance
	CSP	Communication Services Providers
	CSV	Comma-Separated Values
	CU	Centralized Unit
D	DevOps	Software development methodology that combines software development with information technology operations
	DevSecOps	Software development methodology that combines software development with information technology and security operations
	DICOM	Digital Imaging and Communications in Medicine (the standard for the communication of medical imaging information and related data)
	DLT	Distributed Ledger technologies
	DNA	DeoxyriboNucleic Acid
	DTH	Direct-To-Home
	DU	Distributed Unit
E	E2E	End-to-End
	EAFRD	European Agricultural Fund for Rural Development
	EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
	EC	Edge Computing
	EHR	Electronic Health Records
	eMBB	enhanced Mobile BroadBand
	EMS	Element Management System
	eMTC	enhanced Machine Type Communication
	EO	Earth Observation
	ETNO	European Telecommunications Network Operators

	EU	European Union
F	**FAO**	Food and Agriculture Organization of the United Nations
	FOTA	Firmware Over-The-Air
	FSAN	Full Service Access Network, a world-wide industry association of operator companies
	FTTB	Fiber-to-the-Building
	FTTH	Fiber-to-the-Home
	FWA	Fixed Wireless Access
G	**GB**	GigaByte
	GbE	Gigabit Ethernet
	GDP	Gross Domestic Product
	GDPR	General Data Protection Regulation
	GEO	GEOstationary orbit satellites
	GESBA	The Banana Sector Management Company of Madeira Island
	GIS	Geographic Information System
	gNB	Next Generation NodeB
	GNSS-RO	Global Navigation Satellite System - Radio Occultation
	GUI	Graphic Users Interfaces
H	**HARQ**	Hybrid Automatic Repeat Request
	HD	High Definition
I	**IaaS**	Infrastructure-as-a-Service
	IEEE	Institute of Electrical and Electronics Engineers
	IMVF	Instituto Marquês Vale Flor (a foundation for development and cooperation across portuguese speaking countries)
	iOS	Mobile operating system created and developed by Apple Inc
	IoT	Internet of Things
	IP	Internet Protocol
	IPv6	Internet Protocol version 6
	IPTV	Internet Protocol Television
	IT	Information Technologies
	ITU-T	International Telecommunication Union, Telecommunication Standardization Sector
J	**JSON**	JavaScript Object Notation
K	**KPI**	Key Performance Indicators
	KQI	Key Quality Indicators
L	**L2C**	Lead-to-Cash
	LAN	Local Area Network
	LEO	Low Earth Orbit (Satellites)
	LiDAR	Light Detection And Ranging
M	**MAC**	Medium Access Control
	MAR	Mobile Augmented Reality
	MEC	Multi-access Edge Computing
	ML	Machine Learning
	MMORPG	Massively Multiplayer Online Role-Playing Game
	MR	Mixed Reality
	MTK	Mean Time to Know
	MTTR	Mean Time to Repair
	MUD	Multi-User Dungeon
	MU-MIMO	Multi-user Multiple-input and Multiple-output
N	**NB-IoT**	Narrow Band IoT
	NFT	Non-Fungible Token
	NFV	Network Function Virtualization
	NG-PON	Next Generation PON
	NG-PON2	Next Generation PON 2, a 40 Gbit/s capable multi-wavelength PON system
	NGSO	Non-Geostationary Satellite Orbit
	NLP	Natural Language Processing
	NLU	Natural Language Understanding
	NOC	Network Operations Centre
	NPN	Non-Public Networks
	NTN	Non-Terrestrial Network
O	**ODP**	Optical Distribution Point
	OLA	Operational Level Agreement
	OLT	Optical Line Termination
	ONU	Optical Network Unit
	OPEX	Operational Expenditures
	O-RAN	Open RAN
	OSS	Operation Support System
	OTA	Over-the-Air
	OTT	Over-the-Top

P	**P2R**	Problem-to-Resolution
	PaaS	Platform-as-a-Service
	PC	Personal Computer
	PDCP	Packet Data Convergence Protocol
	PHY	Physical layer of the OSI reference model
	PLMN	Public Land Mobile Network
	PON	Passive Optical Network
	PPDR	Public Protection and Disaster Relief
Q	**QoE**	Quality of Experience
	QoS	Quality of Service
R	**R&D**	Research and Development
	RACH	Random Access Channel
	RAN	Radio Access Network
	RCA	Root-Cause Analysis
	REST	Representational State Transfer, an architectural style for developing web services
	RF	Radio Frequency
	RFP	Request For Proposals
	RLC	Radio Link Control
	ROI	Return on Investment
	RPA	Robot Process Automation
	RRC	Radio Resource Control
	RRM	Radio Resource Management
	RTT	Round-Trip Time
	RU	Radio Unit
S	**SaaS**	Software-as-a-Service
	SAR	Synthetic Aperture Radar
	SDN	Software-Defined Network
	SIM	Subscriber Identity Module
	SLA	Service Level Agreement
	SMB	Small and Medium Businesses
	SME	Small and Medium Enterprises
	SMS	Short Message Service
	SNPN	Standalone NPN
	SOC	Service Operation Centres
	SOHO	Small Office, Home Office
	SOTA	Software Over-The-Air
	SP	Service Provider
	STB	Set-Top Box
T	**TB**	TeraBytes
	TECHCO	Technological Company
	TELCO/ TELCOS	Telecommunication Operator(s)
	Thread	IPv6-based networking protocol for IoT
	TM Forum	A non-proft industry association for service providers and their suppliers in the telecommunications industry
	TTK	Trouble Tickets
	TV	Television
U	**UE**	User Equipment
	UMa	University of Madeira
	URLLC	Ultra-Reliable Low-Latency Communication
	URLLC	Ultra Reliable and Low Latency Communications
	US	United States
	USB	Universal Serial Bus
	USD	United States Dollar
	UX	User Experience
V	**VLAN**	Virtual Local Area Network
	VNF	Virtualized Network Function
	VR	Virtual Reality
W	**WHO**	World Health Organization
	Wi-Fi	IEEE 802.11x - Wireless Network (Wi-Fi Alliance)
	Wi-Fi 6	IEEE 802.11ax -Builds and improves on the 802.11ac Wi-Fi standard
	Wi-Fi 7	IEEE 802.11be -Builds and improves on the 802.11ax Wi-Fi standard
	WLAN	Wireless LAN
X	**XGS-PON**	10-Gigabit-capable Symmetrical PON
	xHaul	Converged optical and wireless network solution
	XR	eXtended Reality
Z	**ZigBee**	IEEE 802.15.4-based open global standard for wireless technology for M2M networks

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 for sharing the knowledge resulting from their research and work.

We also want to leave a note of gratitude to all technical and editorial reviewers who did a meticulous job and contributed to improving all articles' quality and excellence and, therefore, 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.

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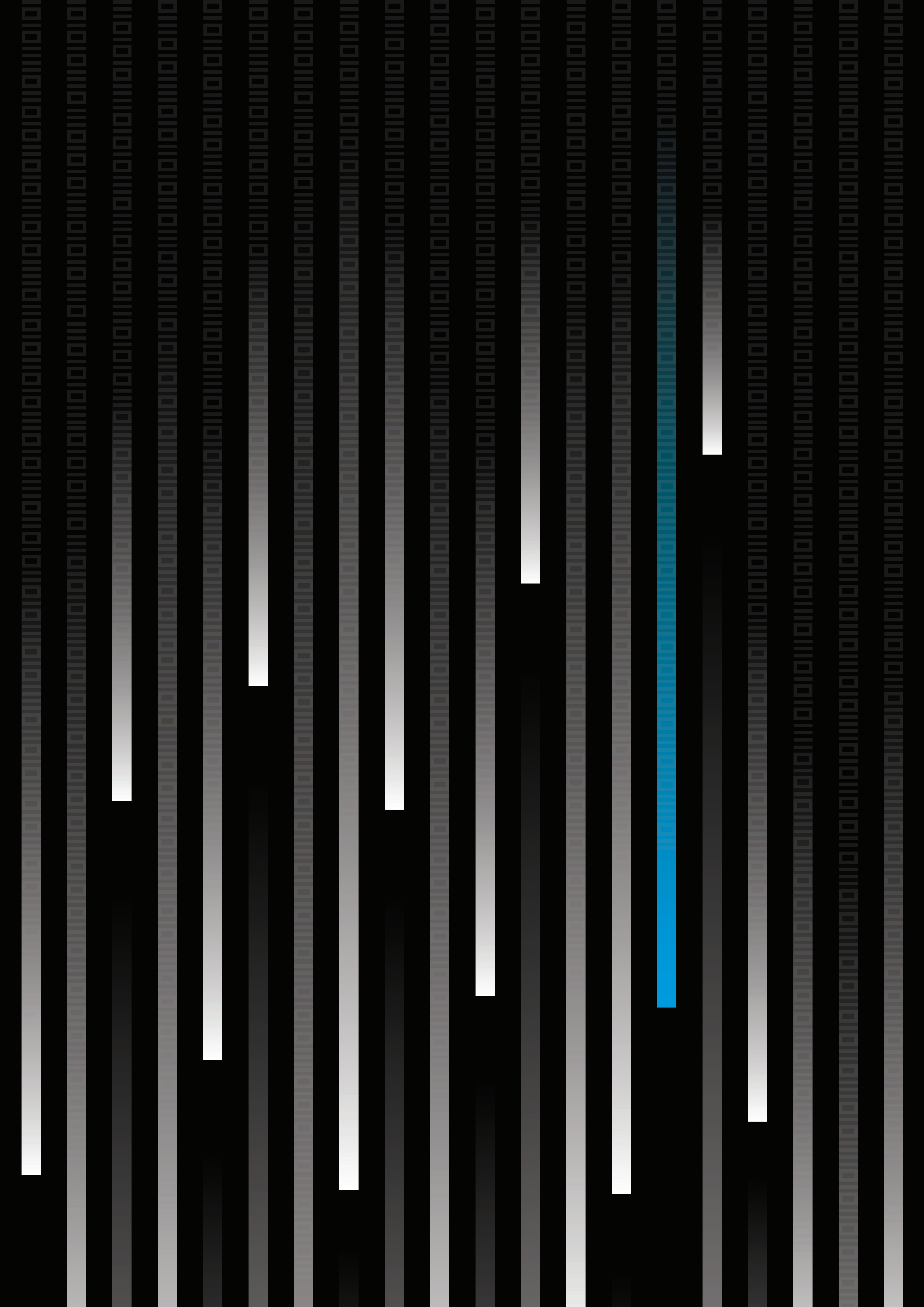
Edition
December 2022



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