White Paper

Mobile Network Technology Evolutions Beyond 2030

April 2024

Contents

Foreword

Telecommunications are on the verge of an exponential innovation acceleration, leveraging and/or empowering the tremendous progress of artificial intelligence / machine learning (AI/ML), cloud computing, platforming, and quantum technologies, among other technological fields. This innovation wave has the potential to deliver strong value propositions for individuals, enterprises and society, at a faster pace than in the past. At the same time, this wave faces significant challenges in terms of environmental impact and sustainability in general, and trust.

Global standards are foundational for modern telecommunications. As the telecommunications ecosystem is about to launch the standardization of mobile network technologies for 2030 and beyond, currently referred to as "6G", this document articulates our thinking at Orange on mobile network technology evolutions for the 2030-2040 timeframe. We will communicate later, on innovation acceleration and value creation in telecommunications.

Key messages

6G has been widely used so far to refer to the mobile technology evolutions to be deployed from 2030. However, we believe the generations terminology fosters misconceptions and may be less relevant in the future for the public. Therefore, we call on the industry to reassess the benefits of using a generation-based terminology for the technologies evolutions versioning, and to focus the marketing and communication on the value enabled for customers and society by new innovations, rather than on the enabling technology.

As indicated in our 2022 white paper [1], we believe that future network technology evolutions need to be designed to deliver value and to be sustainable. We show in this document that value and sustainability according to its environmental, social and economic dimensions, are in fact necessary conditions for the deployment of future networking technologies. In particular, the network technologies to be deployed and operated in the 2030-2040 period will need to support operators in meeting their Net Zero commitments across their fixed, mobile and non-terrestrial infrastructures.

One of the main benefits of future technology evolutions will be to allow networks to accommodate the traffic growth and develop digital inclusion at acceptable financial, energetical, environmental and social costs. In addition, several use cases have been identified with a potential for value and sustainability enablement in various industry and society sectors, that will require enhanced or new capabilities. Further analyses are needed to evaluate the value they will enable to future users, and their relevance from a business, social and environmental perspective.

To this end, we believe it is key that representatives of user communities be associated to the thinking about what future technology evolutions should deliver. These include representatives from vertical sectors, application developers, and the society at large. For the latter, Orange has spearheaded a societal dialogue initiative. As a global technology needs input and feedbacks from different regions of the world, dialogues should be organized with different communities in different regions, through an ecosystem-wide effort.

In terms of user data rate and latency performance, the use cases currently identified for 2030-2040 appear already feasible to some extent with the current or ongoing 5G specifications. However, area capacity needs to be higher than for 5G to support the concurrent delivery for many devices of the high data rates expected by new use cases, especially immersive communications. This capacity expansion needs to rely on the existing macro radio sites without additional densification. We believe that future network technology evolutions should target continuous, gradual network evolutions, rather than a complete redesign of existing systems. Therefore, the benefits and costs of changing the air interfaces need to be carefully weighed, while the future core network evolutions should incrementally enhance the 5G core network mechanisms, for instance leveraging the Service-Based Architecture principles introduced in 5G. Enhanced capabilities for energy optimisation, exposure of network assets, cloud-native implementation, automation and AI/ML should be at the core of the system design, as well as resilience and security. Eco-design is a must, and software upgradability is to be privileged for both network equipment and terminals.

1. Beyond “G’s”, for a new approach of mobile network technologies evolutions

The generational paradigm has been used since the deployment of 2G technologies and has become the traditional way to commercially label major mobile network technology evolutions. However, we think that the time has come to revisit this paradigm. Indeed, the G’s terminology carries several associations which are no longer true and are now misconceptions.

A new G provides a ground-breaking better experience of the mobile Internet: this was true until 4G, which enabled the generalization of mobile broadband, including Internet access and video in mobility. Today, the technical requirements of the services mainly used on mobile networks by the public, social networks and video streaming, are largely compatible with the 4G supported data rates. Consequently, beyond much faster transfer of heavy files, such as movies, arguably 5G did not significantly improve the experience of these services. In fact, the major benefits of 5G so far are not visible to the end users: a cost-efficient capacity expansion solution maintaining excellent experience of mobile services despite a sustained traffic growth every year, and energy savings mechanisms for a much higher network energy efficiency.

Notably, the evolution of 5G remains ongoing with many end users unaware -– the 5G Stand-Alone (5G-SA) currently being deployed will enable new services exploiting its managed latency capabilities such as Extended Reality (XR), as well as disruptive features for virtual private networks like network slicing. 5G-SA is expected to be especially useful for enterprises, with a huge value potential. Therefore, the introduction of disruptive new services or user experience enhancements do not necessarily coincide with the launch of a new generation. Likewise, the innovation in mobile networks addresses multiple services in addition to the mobile Internet.

A new G requires new network equipment, to be added to or to replace the legacy ones, and to change the user terminals, leading to massive cost and environmental impact: Adding a new generation can incur a significant cost, but it does not require theo deployment of a new network. Indeed, the passive infrastructure of towers, cabinets, fibers are common to various generations and represent a large share of a network cost and environmental impact. For instance, Orange deployed 5G mostly on 4G radio sites, thereby reusing the existing masts and civil engineering for energy supply and backhaul. Besides, part of the hardware renewal happens anyway for energy-efficiency and maintenance reasons.

Major technology evolutions often require changing the user terminal to benefit from them. Nevertheless, the introduction of a new technology does not prevent users who wish to do so from continuing to use the legacy one. We observed that 5G has not triggered a significant acceleration of terminals renewal on the Orange footprint, the move to 5G terminals happening mostly as part of the usual renewal of smartphones, for other reasons.

Not much happens in telecoms between the G’s: the emphasis of marketing on generations conveys a misperception of limited innovation between generations. This does not reflect the reality, as 3GPP publishes a new release of the 4G/5G specifications approximately every 18 to 21 months, each introducing several innovations, such as the support of Non-Terrestrial Networks recently. Significantly, the development of cloud-based networking in the coming years will facilitate the deployment of new features in the network as software, resulting in an even more continuous innovation introduction capability.

For these reasons, we call on the GSMA, 3GPP and more generally the industry to reassess the benefits of using a generation-based terminology to refer to the future mobile network technology evolutions. Also, we think the focus of the telecom industry marketing and communication should be on the value enabled to our customers and society by new innovations, rather than on the enabling technology.
In this document, we will often refer to future mobile network technology evolutions instead of 6G.

2. Value & sustainability as core motivation for future evolutions

As indicated in our 2022 white paper [1], we believe that future network technology evolutions need to be designed to deliver value and to be sustainable. We show in this section that value and sustainability according to its three dimensions (environmental, social, economic) are in fact necessary conditions for the deployment of future networking technologies.

Value

The primary purpose of any technology is to deliver value to its adopters. For a telecommunication technology, adopters include end users and operators. For end users, value can take different forms and depends on what matters for an individual, a professional, a company, a digital service provider, a public service, or a community. Designing a technology to deliver value in the 2030-2040 period therefore ideally demands to understand the needs of users and society in this period. This is obviously a very difficult exercise. Nevertheless, we can safely assume that many of the future needs will be the same as today, for instance:

- Remote human interactions
- Remote work
- Access to education, knowledge, and culture
- Environmental sustainability enablement
- Entertainment
- Efficient industries and agriculture
- Efficient healthcare, elderly autonomy

For operators, value includes the capability to accommodate traffic growth in a cost-efficient way and with an environmental impact compatible with Net Zero commitments (see below), reduced operation costs, and increased monetization capabilities, for example via the exposure of assets such as network data or network functions.

Future network technology evolutions can leverage technical progress to enable new services capable of delivering extended value, or to deliver existing services with a reduced cost and/or environmental footprint, while coping with identified challenges and constraints such as the sustainability ones that will be discussed in the next section.

The telecommunication ecosystem has long worked under the assumption that our role was to provide a network technology with always higher performance, and that new applications would appear that would take advantage of this performance and deliver added value to end users. This has been true and can still be in the future. Nevertheless, given the massive investment needed to augment the performance of networks, we need to get some confidence that the technology evolutions being designed will enable return on investment thanks to value-adding services, and/or cost reduction for operators. Without sufficient value, operators will limit their network investments and hence their purchase from network equipment vendors. Value creation for end users and operators is thus a necessary condition for the economic sustainability of the telecommunications industry.

Therefore, we advocate for a paradigm shift towards adopting a value-centered approach for the design of future network technologies. This value needs to be compelling and demonstrable. Given the diversity of users, and the diversity of their needs and contexts in the 2030-2040 period, we believe that interactions between the telecom ecosystem and representatives of user communities are key to understand where value will lie for them, and to construct together relevant services to deliver this value. How to perform these interactions will be further discussed in section 4.

The Key Values (KV) and Key Value Indicators (KVIs) framework has been proposed [2] to depict to what extent relevant values are impacted by a new technology, along with the traditional benchmarks of key Performance Indicators (KPIs). How to define KVs and KVIs, and how to use them in future design works, especially in standardization, is still an open question.
We need also to recognize that new needs and constraints are very likely to emerge that we do not imagine today. Therefore, any future technology must be evolutive enough to accommodate new needs and constraints.

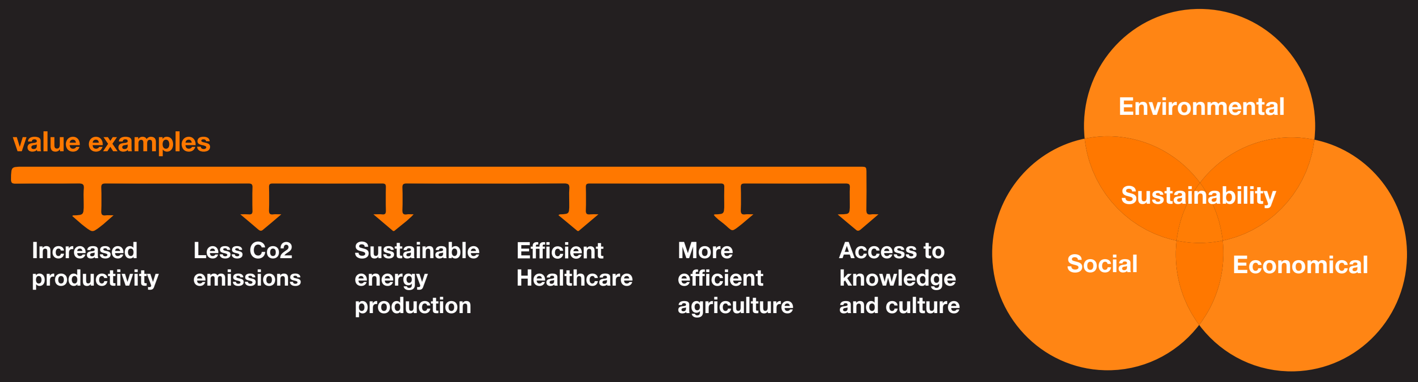

Figure 1: Value examples and the three dimensions of sustainability

Sustainability

Sustainability includes three dimensions: environmental, social, and economic. We describe them hereafter from the specific perspective of networking technologies.

Environmental sustainability targets the preservation of a human and living species-friendly environment. This includes reducing greenhouse gas (GHG) emissions in line with the pathway to limit global warming to 1.5°C above pre-industrial levels, preserving natural resources (e.g., ore, water) and biodiversity. Applied to digital infrastructures, environmental sustainability is mostly about minimizing the energy consumption across the whole life cycle of network equipment and terminals (production, transport, usage, and end of life processing), limiting the need for new hardware for terminals and network infrastructures, and reducing the number of civil work and interventions for maintenance/repair. Indeed, despite efforts towards renewable energy, energy production is still an important source of GHG in many countries; moreover, decarbonation of energy relies also on energy sobriety. In addition, the production of new hardware consumes natural resources, with the mining of its necessary material having potentially significant adverse impacts on the environment. Furthermore, interventions require sending technicians on site, and thus transportation, while civil works need concrete and machines. Environmental sustainability also aims at adapting network infrastructures, equipment, and operations to the climate change. Directions towards environmental sustainability include features for energy use monitoring, infrastructure and resource sharing, the use of low-power components and the possibility to scale down the power consumption according to the load [1]. The adoption of AI features, cloudification and automation solutions can further diminish energy consumption. The incorporation of renewable energy sources and fossil-free electricity, and usage of renewable resources like bioplastics can significantly reduce the GHG footprint. Eco-design [3] of the equipment and terminals, including avoiding hazardous substances, and adhering to modularity, repairability and circularity practices, help to reduce electronic waste generation and to enhance the hardware lifespan, thereby also contributing to reduce GHG emissions.

“Some new network features may not be deployed if it implies missing Net Zero targets”

The social sustainability of networks refers to trustworthiness, inclusion, and social relevance. Trustworthiness includes the availability at all times of the connectivity with the required quality of experience, which is related to coverage, reliability, resilience, as well as security and privacy. Inclusion implies making the technology accessible, from a perspective of coverage, affordability and usability, as detailed in [1]. Social relevance means the technology responds to needs of society and is designed and deployed in a concerted way with its representatives.

The economic sustainability of a technology implies that all the players involved in its value chain (e.g., operators, infrastructure, terminals and components vendors, digital service providers), receive a sufficient revenue so that they can maintain their role. This obviously demands viable business models between the players, which are out of the scope of this paper. But first and foremost, economic sustainability requires the technology to generate revenue and/or a higher cost efficiency so that the associated investments can be accommodated. New revenues require added value creation for the end user, circling back to the necessity of placing added value creation at the heart of the technology design. Economic sustainability also requires network operation to be manageable at affordable costs and complexity. Finally, a common standard worldwide is essential to minimize the costs, by avoiding the need to support multiple technologies in terminals and/or networks, and by enabling economies of scale.

Sustainability a necessary condition for future networks

The three dimensions of sustainability are interdependent and subject to trade-offs in the network deployment. For instance, deploying more radio sites for improved social sustainability through better coverage and inclusion negatively affects the environmental sustainability via a greater environmental impact. Conversely, reducing the energy consumption also reduces the associated expenses, which benefits the economic sustainability, and improves the robustness of the network operation in case of uncertain or unreliable energy supply, thereby also benefitting social sustainability. Consequently, careful considerations are needed to balance the various sustainability goals. However, when it comes to technology design, every effort needs to be made to facilitate achieving sustainability.

This is especially critical because, as we are going to see, sustainability along its three dimensions is a necessary condition for deploying future technology evolutions. First, Net Zero commitments pose hard constraints on the environmental footprint of network equipment and terminals (fixed and mobile). Most operators have committed to become Net Zero at the latest by 2050. Orange has committed to be Net Zero by 2040 (meaning a 90% decrease in carbon footprint in 2040 vs. 2020), and to reduce our GHG emissions by 45% in 2030 compared to 2020 across scopes 1, 2, 3. The GHG cost of the network technologies to be deployed and operated in the 2030-2040 period will therefore directly affect the services able to be offered to society within the constrained GHG budget of operators. In other words, some new network features may not be deployed if it implies missing Net Zero targets, affecting in turn the purchase of network equipment. From this perspective, it is important to understand that the considered network includes fixed, mobile and non-terrestrial infrastructures, so that this global network will need to be more efficient in terms of GHG emissions with future technology evolutions than without. Another dimension of environmental sustainability that we need to consider in the technology design is the future material availability at affordable costs. Indeed, the depletion of the natural reserves of some materials and/or geopolitical tensions, and/or human rights respect can lead to increasing the price of some materials in the next 10-15 years, so that the material requirements of candidate design options should be carefully analyzed, and those involving materials at risk should be avoided.

Social sustainability, in the sense of trustworthiness and social relevance is also necessary for practical technology usage by end users, and hence business, thereby affecting the economic sustainability. The criticality of the latter is obvious, as without it a technology evolution could simply not be practically industrialized or deployed.

Sustainability should therefore impact the design of future network evolutions at all levels: in the envisioned services, in the requirements to be defined as design targets, in the specification of the technical solutions, and in the products design.

We described above the sustainability aspects of the technology. Besides, future network technology evolutions hold great potential to enable other sectors to meet their own environmental, social, and economic targets under environmental constraints. Hence a double-faceted sustainability framework: on the one hand, sustainable network technologies encompassing ecological, human-centric, and economically viable design, responsible use of natural resources, security, affordability, and trustworthiness. On the other hand, network technologies for sustainability, targeting the enablement of innovative and sustainable digital solutions for curbing climate change, protecting ecosystems, biodiversity, and human wellbeing, and facilitating new prosperous business models.

3. Services, use cases and their relevance for users

The technology enhanced performance and capabilities are expected to enable new use cases, or to enhance existing use cases for end users. These use cases evolutions, together with the usage evolutions, will increase the amount of traffic to be delivered by networks.

One of the main roles of future technology evolutions will therefore be to allow networks to accommodate the traffic growth and develop digital inclusion at minimal financial, energetical, environmental and social costs. Efficient capacity growth can be supported by the deployment of new frequency bands on the existing radio sites, exactly as we have done with 5G. This assumes that new bands with sufficient bandwidth and compatible with a deployment on macro networks will be identified, as will be discussed in section 6.

For the past years, several groups and forums have explored and described use cases envisioned for the years 2030s, e.g. NGMN [4] and the Next G Alliance [5]. European project Hexa-X-II [6] built on the work achieved in the previous Hexa-X project (2021-2023) and identified use cases gathered in six areas covering different types of services: immersive experience applied to various areas (entertainment, education, etc.); digital twins; fully connected world (ubiquitous connectivity, Earth monitoring); physical awareness (e.g. network assisted mobility); collaborative robots; and trusted environments [7]. These use cases are described following the guidelines on sustainability elaborated in Hexa-X-II, considering the three pillars of sustainability: environmental, social, and economic sustainability, and the expected value they can deliver.

Among the main use cases envisioned for the 2030s, Orange's 2022 White Paper [1] identified a first set of promising generic use cases, illustrating the potential of future network evolutions to bring value to people and society, and/or support sustainability. This set of use cases is not intended to be exhaustive:

Immersive experience

Video communication has turned into an important tool for work, education, gaming, and personal communication but also to access various services such as health, culture, sports. Future evolutions are expected to transform video communication into fully immersive experiences requiring high quality and possibly multi-sensorial stream.

As we have all experienced, a virtual meeting cannot always replace an in-person meeting. Immersive experience has a strong potential to reduce the number of occasions when a physical trip would be needed, short or long, thereby improving environmental sustainability. Furthermore, it also presents a strong potential to improve teaching and learning for students, improve medical diagnosis in remote consultations, or facilitate access to culture (immersive visit of museum, remote attendance of theatres with the feeling of being in the front row). Beyond enhancing the immersion user experience, future network evolutions should lower the cost of providing such a service, thereby democratizing its access.

Digital Twins

The concept of Digital Twins, a digital model of a physical object, has shown a great potential for exploitation and maintenance of complex infrastructures. It requires an efficient collection of data representative of the physical object and its synchronization in time. Digital Twins can be an asset to monitor and control usage of resources in various environments, enable predictive maintenance to extend the usage of machines, or to reduce the number of engineer interventions. Various sectors can take advantage of them, for example, utilities in smart cities, agriculture, monitoring of wild areas, preventions of natural disasters, and network operations.

Industry & Robots

Robotics in industrial settings represents a strong demand to autonomize manufacturing and large system operations. Future network evolutions are expected to simplify and generalize the capability of supporting reliable and low latency communications enabling robot-to-robot and human to robot collaboration. Usage of robots should generalize beyond the industrial area, for example, assistance for disabled or dependent persons.

Digital Inclusion

Digital inclusion means that connectivity technology should be accessible to all. Currently, some people cannot access Internet services due to coverage, affordability, or skills reasons. Coverage issues especially affect rural areas in Africa, but it can also affect very-low density areas in Europe, as well as desertic areas such as mountains or at sea.
Future network technologies should aim at providing solutions to bridge these gaps and enable access to all. This includes providing cost-efficient coverage solutions for terrestrial and non-terrestrial infrastructures, cost-efficient terminals, and intuitive interfaces to facilitate accessibility.

Healthcare & Well-being

Immersive experience is expected to transform the way patients could benefit from more natural interaction during remote consultation with a physician, leading to improving diagnosis and care of patients. This capability is particularly relevant for areas lacking medical facilities.

The ability to support various sensor and devices can also facilitate the everyday life of people with disabilities. Healthcare therefore represents an activity area with high potential for achieving value for society and people.

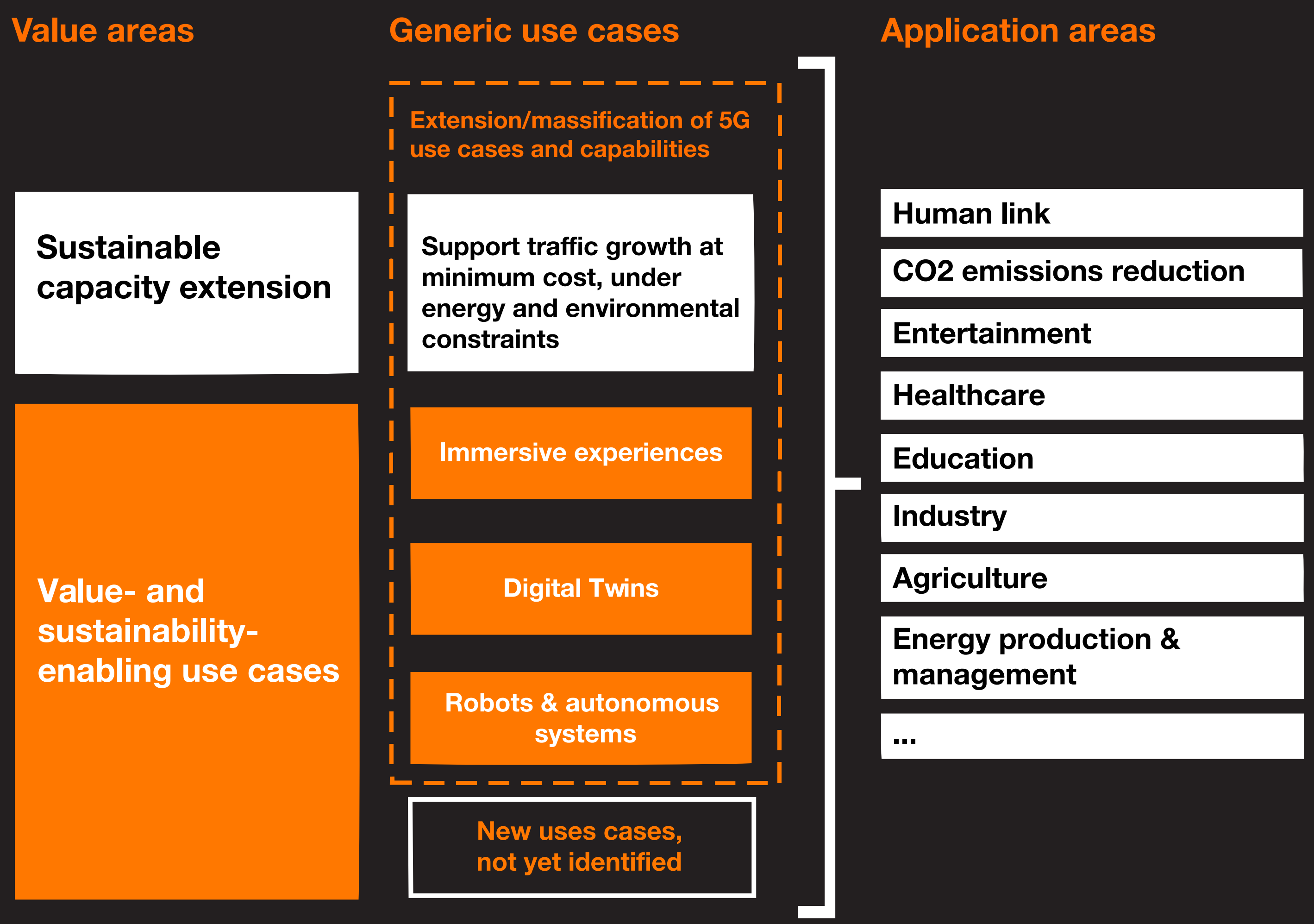

Figure 2: value areas, generic use cases and their potential application areas

All of these use cases are already feasible to some extent with the current or ongoing 5G specifications, for example, with the support of Non-Terrestrial Networks and XR, introduced in 3GPP Releases 17 and 18. Further technology evolutions will enable a continuous journey towards better experience and adoption at scale of more demanding services in terms of data transfer, while at the same time being compatible with Net Zero carbon commitments and the global warming Paris Agreements. Indeed, if these use cases can lead to significant positive social, environmental, and economic impact for our customers and society, their practical deployment will need to be compatible with the constraints outlined in section 2. The technology design needs to facilitate this, otherwise facing the risk of limiting their practical deployment.

Nevertheless, all these use cases are so far generic use cases, imagined mostly by the telecommunications ecosystem and from a technological standpoint. Further analyses are needed to evaluate the value they will enable to future users, and so their relevance from business, social and environmental perspectives. We strongly believe that a particular effort should be put on the design of use cases targeting the enablement of other sectors to minimize their environmental impact, especially to better control and reduce their induced Green House Gases emissions. Various areas (e.g., industry, agriculture, transports) are candidates to benefit from this “enablement effect” towards one or several pillars of sustainability. To maximize the associated benefits, interactions are needed with representatives of these sectors.

4. Towards a new collaboration and societal dialogue culture

As networks are an essential element of the life and activity of citizens, small and large companies, cities, states, and other communities, we believe it is key that representatives of these user communities be associated to the thinking about what future technology evolutions should deliver. On the one hand, it is important to maintain synchronization between technological progress and society, by providing factual information about the technology capabilities, thereby helping to prevent false expectations or fake news. On the other hand, the highest value creation potential lies in co-constructing future use cases and services with their future users. Taking the example of sustainability, working out use cases to enhance the sustainability of specific society sectors requires inputs from these sectors on their issues and future context. This is true for other types of value as well.

Vertical sectors

With regards to the vertical industries such as manufacturing, automotive, energy, etc., external organizations for each specific domain such as 5G Alliance for Connected Industries and Automation (5G-ACIA) [8] or 5G Automotive Association (5G AA) [9] were established during the 5G design timeframe to gather the industry partner requirements and privilege a single channel of communication towards standardization organizations such as 3GPP. These organizations naturally are needed to continue this work in order to contribute to future network evolutions. Further organizations of this type representing other vertical sectors, and today not represented, should be encouraged.

Application developers

An anticipated trend of network evolutions is to increase the exposure of assets such as network data, network functions or other network resources to third parties via Application Programming Interfaces (APIs). This framework will enable application developers to enhance their services and will generate new network monetization opportunities for operators. Therefore, a great value potential lies in sharing mutual needs and constraints between application developers and network operators, to identify the meaningful network assets to be exposed without compromising the network integrity.

Society at large

The preparation for future communication technologies must integrate the wider societal vision. This is a challenge that Orange is taking on by promoting a societal dialogue approach. The goal is not only to gain a better understanding of society's expectations but also to identify appropriate mechanisms for collecting these expectations and creating a relationship of trust. This approach aims to contribute to the European project Hexa-X-II [6].

The societal dialogue consists of an inclusive and collaborative communication process between different stakeholders in society (citizens, civil society organizations, businesses, etc.). It includes a step of presenting issues and information, to "acculturate" on the subject to be addressed during the dialogue. Thus, it is a genuine co-construction process among these actors, with the aim of reaching a consensus situation: the idea is to design technology for society and with society. Orange initiated a series of collaborative workshops in the last quarter of 2023. The first six workshops were conducted with Orange employees, general public customers, and representatives from Lannion City Hall, aimed at testing an initial facilitation method and gathering initial feedback to refine and develop other workshops in different territories and for different target groups. The favored method was Edward De Bono's "Six Thinking Hats" [10], which encourages participants to adopt different modes of thinking represented by colored hats, allowing for a multitude of ideas, postures, and attitudes to be generated. In this process, participants had access to a body of data on network evolution, from the Hexa-X project [11] and Orange's 2022 white paper [1].

From these initial workshops, some insights have been gathered. As these are only early moments of dialogue, concrete results cannot be presented at this stage. Nevertheless, it is possible to identify overarching themes that participants appear to prioritize. Notably, discussions revolve around a perceived technological race, as well as inquiries into the relationship of the telecom ecosystem with the world and the significance of networks in the face of societal resilience. The participants' concerns can be summarized as a desire for a paradigm shift, where the network not only serves commercial interests but also positions itself as a common good, capable of supporting decarbonization and societal resilience. Finally, it is important to note that the societal dialogue approach is very well received by the participants, who appreciated being consulted.

As the dialogue dimension is innovative, an exploratory qualitative approach has been chosen to understand the issues and explore the range of possible behaviors, attitudes, and representations. This initial approach is essential for delving deeper into the subject of future networks, and eventually designing a technology that meets society's expectations. Once this qualitative step is completed, a quantitative approach could help weigh the results collected during the exploratory phase.

Obviously, a global technology needs to collect inputs and feedbacks from different regions of the world, different cultures and different types of people and businesses, which cannot be gathered by a single actor. We therefore invite anyone interested to organize such dialogues within their community and area of presence. Within Orange, we will continue this work with several further interactions planned in 2024, and the results will be contributed to the Hexa-X-II project and published in D1.4 deliverable.

5. Performance requirements

Our 2022 White Paper [1] introduced several requirements. We complement them hereafter with our views on quantitative performance requirements, according to typical Key Performance Indicators (KPIs) of mobile networks. The values are set according to what we think will be necessary for the use cases identified in section 3. 5G performance requirements were ambitious and remain relevant for the considered uses cases. End-to-End latency and reliability were already key performance indicators, and this will continue in the future. But only very specific uses cases (among, for example, industrial use cases) require the most extreme values and are associated with dedicated deployments. Therefore, we expect future network technologies to make the high level of 5G performance accessible to a larger number of devices rather than to improve the maximum performance levels as a given. This involves considering higher connection densities compared to 5G as a consequence of the rise of new terminal types already initiated with 5G.

KPI	Possible extreme value	5G reference [12]	Complement, e.g., target scenario
User experienced data rate (at cell edge)	300 Mbit/s 100 Mbit/s	300 Mbit/s 50 Mbit/s	dense urban other outdoor environments Note: 250 Mbit/s required for immersive experiences. The majority of identified future usages would require less than a hundred of Mb/s.
Area capacity	3 Tb/s/km^2 450 Gb/s/km^2	750 Gb/s/km^2 100 Gb/s/km^2	dense urban outdoor & wide area Note: 30% activity factor assumed
Connection density	35 000 / km^2 15 000 / km^2 1.10^6/ km^2	25 000 / km^2 10 000 / km^2 1.10^6 / km^2	mobile broadband – dense urban mobile broadband – urban macro massive IoT
Positioning accuracy	< 10cm < 1m	1m 3m	indoor deployment outdoor & wide area
Energy efficiency	x10 vs. 5G	no quantitive requirement	at least as much as capacity increase, so that the network energy consumption remains stable or decreases
Minimum end-to-end latency	5 ms 0.5 ms (URLLC)	0.5 ms 0.5 ms	in generic deployments, for services that require it for specific services & uses cases associated to specific deployments
Reliability	99.9 % 99.999 %	idem idem	for most of services, typically (mobile broadband for specific services & uses cases associated to specific deployments
Mobility	500 km/h	idem	for specific services (very high speed trains, planes)

From this table, most of the typical mobile connectivity KPIs that we foresee for future mobile networks evolutions are in the same order of magnitude as those of 5G, and in the lower end of the ranges of estimated targets for research and investigation of ITU IMT-2030 [39]. Indeed, the currently envisioned services and usages do not appear to justify a performance gap compared to 5G per user. However, future technology evolutions should aim at further improving the cost, environmental impact, and energy efficiency in delivering these performance levels for a wider number of concurrent users. In particular, the most disruptive service in sight seems to be Immersive Communication or “XR”. While nobody has the crystal ball on what future XR devices will be, the mix of high throughout and low latency requirements will be highly demanding on network capacity.

This is particularly reflected in the area capacity requirement, that we believe needs to be higher than for 5G and needs to be achieved by relying on the existing macro radio sites without additional densification, together with a significantly higher energy efficiency gain in order not to increase and even reduce the network energy consumption.

The values of the above performance requirements may be revisited in the light of the progress on the identification of relevant use cases.

Additional requirements for system design are not purely performance-related. These include operational requirements, and the following societal requirements introduced in [1]: minimum end-to-end environmental impact, high resilience, digital inclusion, security, and exposure awareness. As they are difficult to translate into quantitative requirements, we indicated in [1] several key design principles and technical enablers to address them. The next sections focus on the design of the system components, providing more detailed technical directions to satisfy performance, societal and operational requirements.

6. Radio access network

Spectrum

Spectrum remains for mobile operators the most valuable and prized asset to boost performance and capacity. With the ever-increasing traffic demand from users, coupled with more and more demanding services, it is expected that additional spectrum will be necessary to sustain the traffic growth by the 2030 timeframe and beyond. For best efficiency and maximized return on investment, spectrum bands deployable on macro networks, thereby reusing existing radio sites, are essential. The example of millimeter wave, whose deployment is still largely at bay in Europe, shows the limitations of short-range spectrum bands in wide-scale deployments.

As such, the most promising band at this stage is the future 6 GHz (6425-7125 MHz) licensed band, identified for Region 1 and parts of Regions 2 and 3 during the latest World Radio Conference 2023 (WRC-23). While its applicability may be equally relevant for the current 5G, its timeframe of availability may be slightly before 2030, making it a strong candidate as a prime band for a future evolution.

Besides, spectrum bands within the so-called “Frequency Range 3 (FR3)”, particularly between 7 and 15 GHz, are also of high interest, and have the potential to be deployed on macro networks with similar coverage as sub-6GHz bands. Several bands in this range have been put on the agenda for WRC-27, and 3GPP has already launched a channel modeling study for this range [13].

At the end of the spectrum, sub-TeraHertz (THz) bands have been subject to extensive research activities, however it seems too early at this stage to consider such bands with extremely short range before the mid-2030s at the earliest.

More generally, re-use of legacy bands should be facilitated. Lessons learnt from 5G show that spectrum sharing with the previous generation is extremely useful, notably to aggregate new and legacy bands in an efficient manner. While spectrum sharing between 4G and 5G suffered from severe overheads due to the lack of lean signaling channel design inherited from 4G, a much more efficient sharing approach seem technically feasible between 5G and its evolutions, with no or only limited overhead. Such “native spectrum sharing” should be a fundamental building block of a future technology evolution, allowing a full re-use of legacy 5G bands from day one and a much smoother spectrum refarming process.

Air interface

On the one hand, the identification of new spectrum bands will inherently trigger the specification of a new air interface, at least for the new bands. On the other hand, the reuse of 5G frequency bands will motivate the reuse of 5G air interface (at least on common bands). The specification of a technology evolution also represents an opportunity to revisit the air interface, as new techniques or enhancements of key building blocks of the air interface have been developed since the specification of the current technology. These new developments could possibly lead, if properly introduced, to important performance improvements and/or savings in energy, depending on directions for optimizations. But the benefits and costs of changing the air interface technologies should be carefully weighed, balancing the possible advantages and gains versus the costs of these modifications (heavy impact on the whole system design, on the manufacturing of equipment and devices, on the possibility to reuse legacy equipment through software upgrade or not…).

Channel coding

New channel coding schemes have been introduced in 5G New Radio (NR) specifications, relying on Low-Density Parity-Check Codes (LDPC) for data channels, and Polar Codes for control channels. A new revolution of the channel coding schemes is not foreseen (expecting that polar codes will be maintained for control channels and LDPC codes for data channels), but enhancements could be envisaged and focused on the optimization of the existing coding schemes to reduce energy consumption. Indeed, channel coding schemes are complex and weight on the energy consumption due to their iterative decoding process.

Massive Multiple-Input Multiple-Output (MIMO)

Massive MIMO is a crucial building block and is essential to deliver enhanced Mobile Broadband services. Several advanced functionalities have been introduced in the various 5G releases in 3GPP, including new codebooks, multiple Transmission / Reception Points (multi TRPs), framework for Coherent Joint Transmission, etc. But there is still work needed to improve their applicability, as their use could be restricted (e.g., by extending the use of the new codebooks to higher number of antenna ports, or in FDD), or challenging in realistic conditions (Coherent Joint Transmission under realistic time/ frequency synchronization is still challenging). Moreover, the traditional codebook-based MIMO approach could be challenged by the emergence of new techniques, such as AI/ ML channel compression and prediction [14]. Therefore, future mobile network evolutions should assess and refine the different MIMO techniques introduced in 5G to improve their applicability and practicality in realistic conditions, while minimizing the impacts on cost, energy consumption, and requirements on the backhaul.

Waveforms

The Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) waveform is specified in 5G and will be necessarily reused in legacy 5G bands. The possibility of introducing a new waveform mainly applies to new frequency bands, and the most appropriate type of waveform will differ depending on the targeted spectrum region. High frequency bands, such as sub-THz bands, may be more favorable to the single-carrier type of waveforms, whereas for new spectrum in the FR3 bands, OFDM waveform could be used as an extension of the legacy design in FR1 and FR2 bands. Consequently, maintaining OFDM waveforms seems the best option, while assessing other waveforms may be suited for new frequency bands.

Connectivity Services

A right balance should be found between introducing innovative connectivity services and capitalizing on legacy technologies whenever possible.

The industry should not reinvent the wheel on services and technologies already efficient in 4G/5G. For instance, massive IoT services can still rely on LTE-M and NB-IoT air interfaces to capitalize on economies of scale.

Besides, other services have required significant attention in 5G specifications, such as Ultra Reliable and Low Latency Communications (URLLC) or Cellular Vehicle-to-Everything (C-V2x) communications, but have not yet materialized in commercial deployments, and others such as satellite access are just emerging. For those, a proper gap analysis between market requirements and existing specifications would be required before redefining a future variant.

Innovations with potential to be confirmed

There has been increasing work recently on innovations and new technologies with possible impact on future specifications [1]. A first case is Integrated Sensing and Communication (ISAC), which is a very active area of research and the topic of early field trials. The development of joint communications and sensing could possibly lead to the design of a specific waveform for new frequency bands (millimeter-Waves / sub-THz bands), and support for the allocation of resources to communications vs. sensing. Sensing performance below 6 GHz is expected to be limited by the lack of bandwidth which reduces the range resolution and accuracy; solutions such as distributing sensing using several base stations are under study to improve the performance in this case. The new FR3 bands offer more bandwidth and should make more sensing use cases feasible. In general, the use cases, performance, and business models of radio sensing in various frequency bands need to be clarified.

Reconfigurable Intelligent Surfaces (RIS) represent another area of research, investigated as a low power and low-cost solution for coverage extension, especially in millimeter-wave frequency bands. Early trials have shown the capability to improve the coverage in areas suffering from poor coverage. However, there are still questions about the maturity, energy consumption, Total Cost of Ownership and deployment of these surfaces, under investigations in collaborative projects and in the ETSI RIS Industry Specification Group [15]. They will need to be assessed and compared with alternatives such as small cells or traditional repeaters.

Zero-energy-device (ZED) are another area of research, identified as a potential ultra-low power solution for Ambient IoT services. These energy autonomous devices may use backscattering to transmit information and harvest ambient energy (such as solar, vibratory, thermal, RF energy, etc.) to power themselves and are associated with limited storage capabilities. Trials have demonstrated basic capabilities to detect tag-like devices, but further investigations are needed to confirm the business potential and technical feasibility of the use cases.

7. Optical networks

Optical communications ensure most data transfers in telecom networks, the mobile traffic being often transported over optical fibers from the radio site to the mobile core network, together with other traffic from a wide range of market segments (residential, enterprise, etc.). Both optical access and transport networks are key infrastructure to support the evolution of connectivity and network functions towards future networks, while constantly improving the energy consumption. It must be also noted that the fiber passive infrastructure is sustainable over the long term (>20 years); only active equipment may be updated following mobile capacity demands.

Fiber to the Antenna (FTTA) is instrumental in driving the advancement of single fiber bidirectional Point-to-Point (PtP) interfaces to accommodate higher data rates. Indeed, the Optical Line Terminal (OLT) evolution will be mainly driven by PtP applications for FTTA [16] that are likely to be the first to require increased performances in terms of line rates of interfaces in order to support mobile network capacity increases. As the PtP interfaces, 10G and 25G today, coexist with Passive Optical Networks (GPON and XGS-PON currently) for FTTH and enterprises in the OLT, all access networks' topologies and market segments will benefit from these evolutions. The OLT will be capable of supporting the coming standardization items at ITU-T: 100G-PtP interfaces [17, 18], and 50G-PON [19] to meet demands for ultra-high-speed access network interfaces. Interoperability of optical access systems and RAN systems from multiple vendors is key and is being discussed in O-RAN.

To meet the expected capacity growth while reducing the energy consumption and environmental impact, the Innovative Optical and Wireless Networks (IOWN) Global Forum [20] has introduced a new network architecture called the Open All-Photonic Network (APN), supported by Orange. The APN concept involves optical components such as optical switches for networking purposes, to significantly reduce power consumption compared to electrical packet processing. If the full APN promise is not expected to be deployable before 2040, a growing number of components moving some electrical processing into the photonic domain are expected to appear in the 2030s.

In addition, the evolution of OLTs with Software-Defined Networking (SDN) is bringing significant changes to the way OLTs are managed, enabling various advancements such as OLT managers becoming controllers, cooperative configurations, PON slicing, and hardware disaggregation [21].

On the optical transport network side, growth can be achieved by increasing the capacity per wavelength and the number of wavelengths in use. To respond to the growing traffic demand, the data-center interconnect (DCI), metro-regional and long-haul optical networks use wavelength which carries ever-increasing data rate, e.g. 400G, 800G and 1.6T per channel for the most recent ones. Machine learning and neural networks should also permit to simplify the ever more complex digital signal processing (DSP) and should appear in the up-coming years, for instance to ease the mitigation of non-linear effects in fiber or to make more efficient advanced DSP algorithms [22].
As the spectral efficiencies of transmission techniques for optical transport networks are near the Shannon limit, continuous capacity growth will require multi-band transmission techniques. New amplification bands (O, E, S, C, L, U bands from 1300 to 1700 nm) in the standard single mode fibers (SSMF) already deployed in most optical networks can offer a 400-nm bandwidth. Then ~200-Tbps could be propagated on a single fiber, over several hundreds of kilometers. Multi-band transmission targets especially metro regional transport networks. But it still requires the development of new optical amplifiers and ROADMs which is a very active field of research today [23]. The use of multimode (few modes) or multicore fibers to increase capacity of optical networks is a long-term prospect and is probably more suitable for submarine applications.

The introduction of SDN architectures in the optical transport networks will enhance the capability to automate operations [24], simplifying the network operation, improving time to service and resilience but also providing access to almost real-time data from the network thanks to telemetry. This huge amount of data could be exploited using artificial intelligence to transform the network operations ranging from decision assistant tools to fully autonomous processes. Promising use cases where AI could add significant value include the assessment of the quality of optical transmission [25] and the automation of fault management function [26].

Openness and interoperability are key enablers to operators to achieve optical network automation. Therefore, efforts in open-source communities and standardization bodies are required to provide reference implementations and enable open and interoperable transport network automation.

8. Core network and E2E architecture

The mobile network core is evolving with each mobile network generation. The 4G Core Network (EPC) has introduced separation of Control Plane (CP) Network Functions (NFs) and User Plane (UP) NFs. This approach has enabled independent design and placement of CP and UP NFs in a cloud-based environment. The 5G Core (5GC) has a higher degree of decomposition, provides flexible interactions based on a Service-Based Architecture and allows the secure addition of new NFs that may interact with the existing NFs to create customised services such as network slicing, context-aware services, services supporting UAVs, C-V2X, etc. The Network Data and Analytics Function (NWDAF), an NF of 5GC, provides data collection from other NFs, performs their analysis (trends and predictions) and the results can be exploited for intelligent and autonomous network operations, management, and orchestration. NWDAF shows an essential trend in collecting and exposing information about the network state to service and management platforms for adaptive network and service behaviour.

The way of implementing 5G core networks in practice, especially in the Stand-Alone way, can vary from one use case to the other. Operator-grade core networks can be directly installed on the infrastructure provided by the vendor or installed on the Telco Cloud infrastructure of the operator (see section 9). Only this last mode allows the mutualization of the infrastructure between network functions from several vendors.

We believe future network technology evolutions should target continuous, gradual network evolutions, rather than a completely new system. Therefore, a future core network should incrementally enhance 5GC mechanisms and support future use cases. Any architecture evolution should aim at both flexibility and simplicity. As such, re-using the principles of the 5G flexible Core Network is preferred, relying for instance on the principles of Service-Based Architecture to introduce new modules for future evolutions of the core network.

Architecture options to connect the RAN and the core network should be reduced to the strict minimum, potentially Stand-Alone (SA) only.

Main future core network-related requirements include:

- **Energy optimisation:** Support of advanced, cross-layer and cross-domain mechanisms for energy consumption optimisation, for the functions of the core network itself and those of the other network segments (e.g., the RAN).
- **Integration capabilities:** Ability to dynamically integrate already deployed mobile and fixed networks as well as newly developed networking concepts, including Non-Terrestrial Networks (NTN), with efficient use of all available networking and compute resources.
- **Network exposure:** New methods of service creation by securely exposing relevant network features, network control and data analytics to third-party applications. Exposure can be done at different levels, such as exposure of information about the network, the service or more deeply, exposure of some configuration interfaces of certain network segments. This requirement means the ability of the CN to store, process and expose information obtained from different sources (including terminals) in line with the data-centric networking paradigm (see below).
- **Operations automation:** Automated, adaptive, and fast CN operations can cope with dynamic network topologies and changing demands as well as unpredictable events (e.g., disasters).
- **Simplicity and flexibility:** Relatively low level of complexity of CN by design, based on proper separation of concerns and a new approach to signalling, for instance new communications schemes between NFs of the CN (e.g., publish subscribe) or event driven architecture as a new communication paradigm between the functions of the CN and the user.
- **Continuous upgradeability:** This can be achieved by decomposing the CN into a set of highly granular services that can be flexibly added, removed, or modified during runtime.
- **Scalable operations and controlled performance:** This requires the specification of relevant KPIs and the definition of monitoring systems as well as adequate data mining facilities to produce these KPIs.
- **Native AI/ML:** a future technology evolution should be “AI/ML-native”, i.e. incorporate all the necessary means to support and leverage AI/ML wherever suited, with an overall architecture adapted to the management of AI/ML models and associated data collection, with operator control on them. The O-RAN Alliance provides an example of an architecture that natively supports AI/ML, see section 10.
- **Cloud-native implementation:** Deployment of CN and RAN in a distributed cloud environment should be possible from day one, to benefit from the cloud-native resource scaling mechanism and dynamic placement of network functions. See also section 9.
- **Multi-provider environment –** the CN should be able to operate securely in a multi-provider environment (including multiple cloud providers) using different trust models for enforcing trust between actors.

The future CN is expected to leverage concepts already used in 5G, such as Service-Based Architecture, network virtualisation, network analytics and network slicing. This CN will need to be implemented with the most recent software technologies and be designed to enable evolutions while keeping the same interfaces. The following paradigtms are identified to be used in the design of the future CN, either as implementation methods or as functionalitiesb (some of them requiring standardization) :

- **Network-of-Networks (NoN)** concept, which lies in the ability to dynamically integrate multiple access networks, transport technologies and complete networks. NoN includes integration of Terrestrial and Non-Terrestrial Networks (satellites at various altitudes: high-, medium-, and low-orbit, aircrafts, High Altitude Platforms, and UAVs), private networks, legacy 4G/5G networks, fixed networks, etc. The multi-homed terminals, nodes or network functions should be able to use multi-connectivity for load-balancing, by exploiting multiple connectivity interfaces to balance traffic to achieve some optimization objectives (e.g., maximize bandwidth, reduce latency, etc.). NoN can also increase resilience by facilitating service continuity across different networks, in case of failure of one of them. At last, NoN can facilitate infrastructure sharing, thereby decreasing resources usage, energy needs and carbon emissions.

- **The micro-service approach:** the CN can be decomposed into microservices hosted in clouds; a single virtualised network function can give rise to a set of microservices, which can be modified (deleted, restored, moved, scaled up or down, etc.) on the fly without service interruption. This capability of individually managing microservices without affecting the global function is a big promise of the cloud-native approach.

- **Intent-Based Networking (IBN):** An intent is defined as “an abstracted, declarative and vendor agnostic set of rules used to support the full lifecycle (Design/Build/Deploy/Validate) of a network and services it provides”. Intent-Based Networking contributes to simplifying the design of network functions and the interactions between network domains, by removing the need for them to adhere to rigid interfaces between them.

- **SDN or Segment Routing:** The User Plane may benefit from concepts like SDN or Segment Routing. Such approaches provide much higher flexibility than the tunnelling approach used in previous generations of mobile networks.

- **Data-centric networking:** : In this concept, a computing infrastructure combined with network control tools (e.g., data paths established by SDN or even MPLS) allow the establishment and the flexible placement of data pipelines, including data processing and storage functions, while dynamically selecting data transfer and network protocols on a pipe-by-pipe basis. The data is a reusable asset, and the value of data can be amplified as it is shared and traded with third parties. As mediators for data sharing and trading, services exploiting data can contribute to valorise the data and enable a data-driven control architecture.

- **Cloud Continuum:** The Cloud Continuum concept gives the possibility of flexible placement of virtualised functions and their easy migration from the end-user terminals up to clouds inside or outside the network or vice versa. As an example, some functions can be placed as close as possible of the end user, possibly in the end device, to save bandwidth in the network and reduce latency in the execution of a global function. Conversely, some computing intensive functions can be migrated to a cloud with more computing power.

9. Cloud-native network

Telcos launched a transformation towards fully virtualized networks many years ago, decoupling the software from the hardware for network functions. This transformation emerged with high promises in terms of operational costs reduction and faster time to market.

Global Telcos such as Orange are today at different levels on this transformation path, some are still in early lab experimentation, some are in trial phases and others already have significant Virtualized Network Functions deployments.

From various experimentations and deployment efforts in the past years, two major pillars are today clearly identified as key factors for the network virtualization success.

Telcos should keep control on the Telco Cloud infrastructure

This is the cloud infrastructure that will be used to host the virtualized network functions. Telcos should be able to easily deploy their Telco Cloud infrastructure, whenever they want, wherever they want, using various solutions and components and with the capability to change easily between any of them. Unlike other types of workloads, network functions have very specific requirements that should be provided by the hosting cloud infrastructure. To achieve the promise of flexibility and operation gains expected from network function virtualization, it is mandatory that Telcos have a way, whenever needed, to update any of the components of this Telco Cloud infrastructure. The updates involve the automatic deployment of upgrades, bugs corrections, security patches or new components for any Telco Cloud element daily (and even more) without impacting the running services. In addition, Telcos should be able to adapt the deployment of this Telco Cloud to their various needs, going from centralized deployments (few to tens data centers per country), to a massively distributed deployment, especially for the needs of Cloud RAN. The tooling adopted by Telcos for the life cycle management of the Telco Cloud should be designed during the early development stages, to support any combination of these deployment models with no subsequent development or engineering efforts.

Network functions should be Cloud Native by design

Taking full benefit from network virtualization cannot be achieved by simply packaging existing traditional network functions as monolithic bulky software binaries to be deployed on the Telco Cloud as a huge virtual machine or even containers. Network Functions should be, at the design stage, architected as individual components as small as possible, co-operating among each other through standard and well-defined interfaces to deliver the network service. This design is at the heart of the Cloud Native paradigm that is already widely adopted in non-Telco IT applications and that has proven huge gains in terms of operational costs. Having network functions decomposed into small pieces opens the door to adopt the rich and tremendous ecosystem of Cloud Native solutions to operate these network functions.

Requirements related to these two pillars have a lot in common: it is all about automation of software operations, simpler system components evolutions and easy adaptation to various network functions needs. By 2030, our vision is to reach a common and unique set of solutions for the life cycle management for both the Telco Cloud and Cloud Native Network Functions deployed on top of it. A key ingredient to achieve this vision is to adopt whenever possible operations using declarative and intent based automation and GitOps principles [27] as the foundation for the management of everything we deploy. GitOps combined with the powerful tooling of Cloud native operations provided mainly by the Cloud Native Computing Foundation [28] ecosystem, should be the cornerstone to build this vision.

Orange, in partnership with other European Telcos (Deutsche Telekom, Telefonica, Telecom Italia, Vodafone) and other partners (Nokia, Ericsson, SUSE…) launched at the end of 2022 the Sylva initiative [29], a Linux Foundation Europe-hosted project that aims at developing an open-source sovereign Telco Cloud infrastructure and its life cycle management tooling, fully adopting Cloud Native and GitOps principles. Orange and other Sylva partners are putting significant efforts to strengthen the Sylva stack proposal, including both broadening the features coverage and enhancing the Sylva code maturity.

Sylva is the first step towards reaching the vision stated above, that we expect to be fully realized by 2030. Future network evolutions beyond 2030 will therefore have to be compliant with the Cloud Native framework described above. The challenge in the coming three to five years will be to have a clear view on how to manage the life cycle of network functions on top of Sylva, relying on the same technical approaches and providing the full flexibility to the Telco in controlling the network functions life cycle. This does not exclude having some specific proprietary pieces for the management of the network functions, but we should be able to seamlessly integrate them with no need for complex engineering or development efforts.

Other challenges include cloud provisioning (multi-provider, multi-technology including Cloud RAN, Edge), scaling with the load increase, abstraction layers for hardware acceleration and access with standardized APIs.

10. Network management

Automation and AI/ML

Future network evolutions should use embedded, cooperative AI/ML-driven operations per node, domain and/or system plane. AI/ML models can be used for data analytics (also per network function), data series predictions, anomaly detection, resource allocation, performance optimisation, security, etc. The O-RAN Alliance [30] describes an architecture that natively supports AI/ML with the goal of automatically and autonomously managing and optimizing the network. The automation of the AI/ML life cycle represents a continuous process, encompassing data preparation model training, evaluation, deployment, and monitoring, and is referred to as Machine Learning system Operations (MLOps). Automation allows to chain and trigger workflows to achieve certain tasks. Autonomy goes one step beyond, with the capability to monitor the AI/ML models and, when necessary, retrain, adapt, or change the ML model itself. These capabilities are provided by AI/ML Workflow services within the Service and Management Orchestrator (SMO) and are supported by open interfaces. To manage applications empowered by AI/ML models, O-RAN specifies controllers: Non- and Near-Real-Time (RT) RAN Intelligent Controllers (RIC) in the management plane (i.e., the SMO) and control plane, respectively. The RICs host and manage the applications that can control and optimize network parameters and procedures. In future network evolutions, AI/ML functions could be further distributed to the base station and the user equipment, thus enlarging the role of the controllers to manage such distributed AI/ML models. O-RAN also envisions generalizing the role of AI/ML to end-to-end (E2E) optimization, by providing cross domain management and orchestration capabilities.

Management and orchestration should be geared towards automation across a multi-domain and multi-technology network, encompassing the RAN, Core and Transport Networks. The SMO should enable efficient coordination between network functions and services across the network domains. Open interfaces will simplify integration, smooth evolution of the network and its automation. This includes open APIs within the SMO, thus generalizing the O-RAN Decoupled SMO to cross-domain. A central building block of E2E automation is cross-domain AI, with cross-domain data management capabilities including unified data ingestion model, data exposure and sharing between network domains, while ensuring data security and privacy. The SMO will support intent-driven management with the capabilities to process and fulfil the intents (see section 8), leveraging on cross-domain AI.

Network digital twins

Digital Twins are widely identified as a key enabler for digitalization in numerous vertical markets or industries like Smart Building, Smart City or Smart Industry. Likewise, digital twins emerged as a cornerstone of tomorrow's network management, to support AI and automation at large. More precisely digital twins are expected to fuel MLOps, and to expose to ML algorithms the knowledge based on the collection and aggregation into digital twins of data from multiple underlying (network) data repositories. A variety (illustrative and non-exhaustive) of possible usages of the digital twin approach in the context of future network management is introduced below.

Telco sites management and field service management: this is the most common usage in the deployment of a digital twin for networks today. Sensors' data (e.g. image, temperature, position) can be collected from telco sites (e.g. with drones).

This data can then be pushed to a digital twin of the site to detect anomalies, provide information to operations and field teams before they go on site.

Platform for "What-if" scenarios: simulation is a recurrent usage of digital twin which allows for the evaluation, test and comparison of different reconfigurations and globally change scenarios, assess the resilience of the network, train teams to handle complex events that cannot be assessed directly using the operational network, test and optimize new services before deployment in production.

Support operation automation: the ability to federate monitoring and supervision data and tools from all the network segments and layers (access, transport, business services) allows for reactive, dynamic, and automated operations of the network. The digital twin can help by providing a single-entry point for operations on the complete life cycle of networks and services, from definition to decommission.

Inventory: digital twins can also be used for the inventory of network equipment and keep track of their evolving configurations during the network life cycle. A digital twin can also help in sharing information and knowledge between the different involved teams, as well as external actors (e.g. subcontractors).

To enable the various network digital twin applications, any piece of network equipment should be delivered with documented standardized data models. In addition, standardized APIs should enable interaction with the equipment manager or the equipment itself to access its data and/or functionalities. For equipment simulation, a behavior model of the equipment would also be useful, including its energy consumption model.

Resilience

Resilience refers to the capacity of the network to ensure reliable and continuous services for customers. A resilient network ensures service coverage and has the capability to recover from interruptions caused by factors like natural disasters (expected to increase in frequency due to climate change), hardware and software failures, cyberattacks, and network congestions. It involves building a robust and flexible system that can effectively manage and overcome these disruptions.

The resilience and availability of future network evolutions require planning for mixed operation with current 4G and 5G networks. This includes redundant infrastructure and security mechanisms for current and future usages, taking into account different resilience requirements for different services (e.g. we should expect more robust emergency call services than streaming ones). To increase coverage and service availability, especially in emergency situations, interoperability with other wireless networks like Wi-Fi is desirable. In addition, integration with non-terrestrial networks can provide additional coverage in remote areas or when the terrestrial network is damaged. High resilience can be achieved through rigorous design and planning, local energy storage concepts, and digital network twins for testing and predicting system behaviors [31].

Building a resilient network comes with several challenges: self-healing is required to manage and mitigate network anomalies in an automatic way to ensure uninterrupted connectivity. AI-based solutions, as investigated in O-RAN, can enable predictive maintenance and help in managing automatic network reconfiguration. The main challenge of resilience lies in balancing the costs associated with implementing different levels of resilience, which often requires redundancy of equipment and fiber infrastructure, as well as maintaining intervention teams. Similarly, optimizing the network infrastructure to minimize power consumption while maintaining resilience is a challenge. Lastly, resilience is heavily connected with security, discussed in section 13.

11. Devices

New types of devices beyond smartphones are expected to appear to enable future use cases. Telepresence and immersive experiences entail advancing headsets for enhanced user comfort, lighter designs, and a more immersive experience extending to the transfer of touch, smell, and taste. Robotics use cases will foster the evolution and broad accessibility of lightweight robots. Extensive sensor deployment for digital twins will demand energy-autonomous sensors. Personal health monitoring devices, to be worn or even ingested, will impose specific requirements for safety, privacy, and adherence to medical regulations. The integration of sensing capabilities is anticipated to be intrinsic to devices, encompassing both sensors and communication devices.

As we see the potential of future devices in supporting new services and redefining human-digital interactions, it becomes imperative to consider the environmental footprint of these devices. The concept of eco-design offers a promising framework for integrating sustainability principles into the development and manufacturing of the future devices. By prioritizing sustainable materials, energy efficiency, modularity and end-of-life management, device manufacturers can mitigate the environment impact of their products, while meeting the demands of an increasingly eco-conscious consumer base. To address such stringent requirements, the design of new devices should target properties such as longer lifetime, modularity, recyclability, energy autonomy for certain IoT use cases, and even sometimes biodegradability.

Also, we encourage the industry to evaluate the cost impact of enabling a higher software upgradability of terminals, to extend their usage duration. The considered upgrades involve compatible radio or core network technology evolutions and features to facilitate the introduction of new services for customers. Such a flexibility would also enable a continuous introduction of new features for network and terminal energy efficiency. Obviously, the required software modifications need to be compatible with the terminal hardware (same processing power requirements, same frequency bands), which prevents some types of evolutions to be eligible.

12. Migration and backward compatibility

A 6G terminal should be able to work within 5G spectrum, with appropriate spectrum sharing mechanisms if the 6G physical layer is different. In addition, the terminals flexibility for software upgrades of networking features and new services is to be investigated, as stated in section 11. This would allow introducing new services on terminals already deployed on the field, supporting continuous service evolution with limited environmental impact.

At the network side, software upgrades of network equipment or cloud-based network infrastructure should be privileged to save on new material. In case new hardware is required, the hardware impact should be minimal (upcycling rather than full replacement). Architecture options to connect the RAN and the core network should be reduced to the strict minimum, potentially Stand-Alone (SA) only.

13. Security

As in the current 5G, the future network access will need to be secured: mutual authentication between the UE and the core network, anti-replay protection, integrity and confidentiality protection of the signaling and the user plane as well as the privacy of the communications and user data. Universal Integrated Circuit Card (UICC) and embedded (e)UICC technologies [32] remain the best solution as of today for the secure storage and processing of the network access credentials in the UE. Remote SIM Provisioning [33] technology developed by the GSMA provide the necessary architectures, mechanisms, and security for the provisioning of the credentials in the eUICC for a variety of use cases (M2M, IoT, consumer devices).

The 5G architecture is still evolving towards open paradigms to become one of the main characteristics of 2030-2040 networks. Two paradigms addressing the future openness needs will impact existing security models: Cloud Continuum, which proposes models for sharing resources distributed over the whole infrastructure, and Network-of-Networks (NoN) proposing accurate cooperation and on-demand or dynamic integration between segments of different nature and vendors to deliver a composite network (see section 8).

In the future, we will move from infrastructure claims as ‘trusted’, to the necessity to deliver in near real time and on-demand evidence that the infrastructure involved in delivering a service is ‘trustable’. Another aspect to be integrated in the future security landscape is linked to the evolving regulation environment (EU CSA, NIS2, IA, CRA, DORA, etc.) in which each stakeholder will become more and more liable regarding their contributions and real-time impact to the end-to-end service delivered or operated. In particular, the EU Cyber Resilience Act [34] and NIS2 Directive (penalties dimensions) [35] may impose to telecom operators to manage their supply chain and more generally the related liabilities chains.

Trust and Liability concepts will apply to all aspects of end-to-end connectivity, to deal with malicious players and vulnerabilities, while keeping the network open and available to all users within digital sovereignty constraints. This requires formalizing the notion of trust domain, of handover while changing domain, and to reach simple security objectives or Standardized Security Level Agreement (SLA). This implies defining and standardizing models, architectures, policies, and mechanisms about trust and liability management beyond 5G.

The network architecture should be enhanced as well as the network elements to ensure end-to-end network security in a virtualized, multi-party, multi-technology communication environment, with software supply chains involving different players.

The impact of quantum computing and communication on the cryptography of future mobile networks should be assessed. Post-quantum cryptography still needs to gain in maturity as it is evidenced by the recent devastating attacks on some of the NIST proposals [36, 37, 38]. It is expected that relevant solutions will be available by 2030, however there is a need to get confidence on these solutions and to improve their efficiency.

Artificial Intelligence (AI, including large language models) has a versatile dual use. AI enables automating threat management in a heterogeneous and global environment, unifying security function softwarization and virtualization to prevent, detect, and mitigate threats optimally. However, it can potentially be used by cybercriminals to conduct cost-effective large-scale attacks, therefore the risks posed by such technologies should be also anticipated.

In general, compliance with current and new regulatory constraints related to security, privacy and liability and associated certification schemes will need to be anticipated.

14. Standardization

As with previous generations, Orange sees 3GPP as the prime organization to lead the specification of a universal standard for future mobile network evolutions. The values of a single standard for mobile technology have been proven, from global interoperability to economies of scale. As such, the industry seems currently well aligned in avoiding any fragmentation, and Orange strongly supports this view.

We believe there is no rush for 6G standardization and commercialization. The services and market requirements in the foreseeable future are expected to be supported sufficiently by the 5G networks, including AI/ML and Cloud technologies, which are under further enhancements in 3GPP standards. Also, sufficient time needs to be allowed to collect feedback from the field operation of the latest 5G features, to specify their enhancements in the most effective way. Therefore, no urgent need is foreseen for the commercialisation of a network evolution standard addressing the 2030-2040 timeframe before 2030 or even 2032.

However, we recognize that the 3GPP standardization timeline is constrained by the ITU-R timeline for IMT-2030 [39]. While the IMT-2030 is due in 2030, the evaluation phases of candidate technologies span across 2028 and 2029. At this stage the overall 3GPP standardization timeline is still under discussion. While some companies propose completion of the first 6G specifications by beginning 2029, we believe there is no urgency to speed up specifications and that completion by end 2029 would still be compatible with the ITU-R submission. The most important aspect is to focus the specifications on a reasonable number of features or technical options answering clear business needs and that have a high chance of deployment.

While 3GPP is the main standardization body for mobile networks, other Standard Developing Organizations (SDOs) are expected to play a significant role in complementing the standards for future networks. Now well established in the ecosystem, the O-RAN Alliance is seen as the leading forum for the specifications of cloud-native infrastructure, from open interfaces to cloud orchestration and intelligence. While the O-RAN Alliance is expected to naturally extend its specifications to 6G, the respective roles of 3GPP and O-RAN Alliance may need to be further discussed, to maintain a clear split of activities and avoid any overlap. Other forums will also play a role, such as the TM Forum [40], which has recently taken a prominent role in leading the specification of Open APIs.

As detailed in section 4, we believe co-design of future use cases and service requirements with customer and service provider communities can only increase the confidence of our industry in defining a meaningful technology for future needs. Dedicated industry associations like 5G-ACIA and 5G AA already represent in 3GPP the sectors of industrial automation and automotive, respectively, and expected to continue this role in the future. Further organizations of this type representing other sectors, and today not represented stakeholders like societal stakeholders or smaller businesses would be useful and should be encouraged. Reflecting societal inputs would be especially relevant at the earliest stages of the standardization process, during the use cases and service requirements study. One way of achieving this is to invent new ways of incorporating the identification of value in the standards work, as spearheaded by the Key Value Indicators (KVIs) approach that started to be discussed in 3GPP. Another way is to build confidence on the technology relevance outside of standardization, e.g. via the societal dialogue approach discussed in section 4.

Societal inputs should then be collected by various organisations, and possibly aggregated by other organisations, e.g. ETSI, GSMA, or others, in order to be contributed to 3GPP by 3GPP members. The specification phase (Work Item in 3GPP) is expected to happen from mid-2026 for 6G, which may be compatible with the timeline needed to run sufficient societal dialogues.

Overall, we should strive for achieving a reasonable confidence in the business potential of future technologies before making structuring decisions in standards, even if it means potentially delaying standardization.

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