orange™

White Paper

Orange's vision for 6G

March 2022

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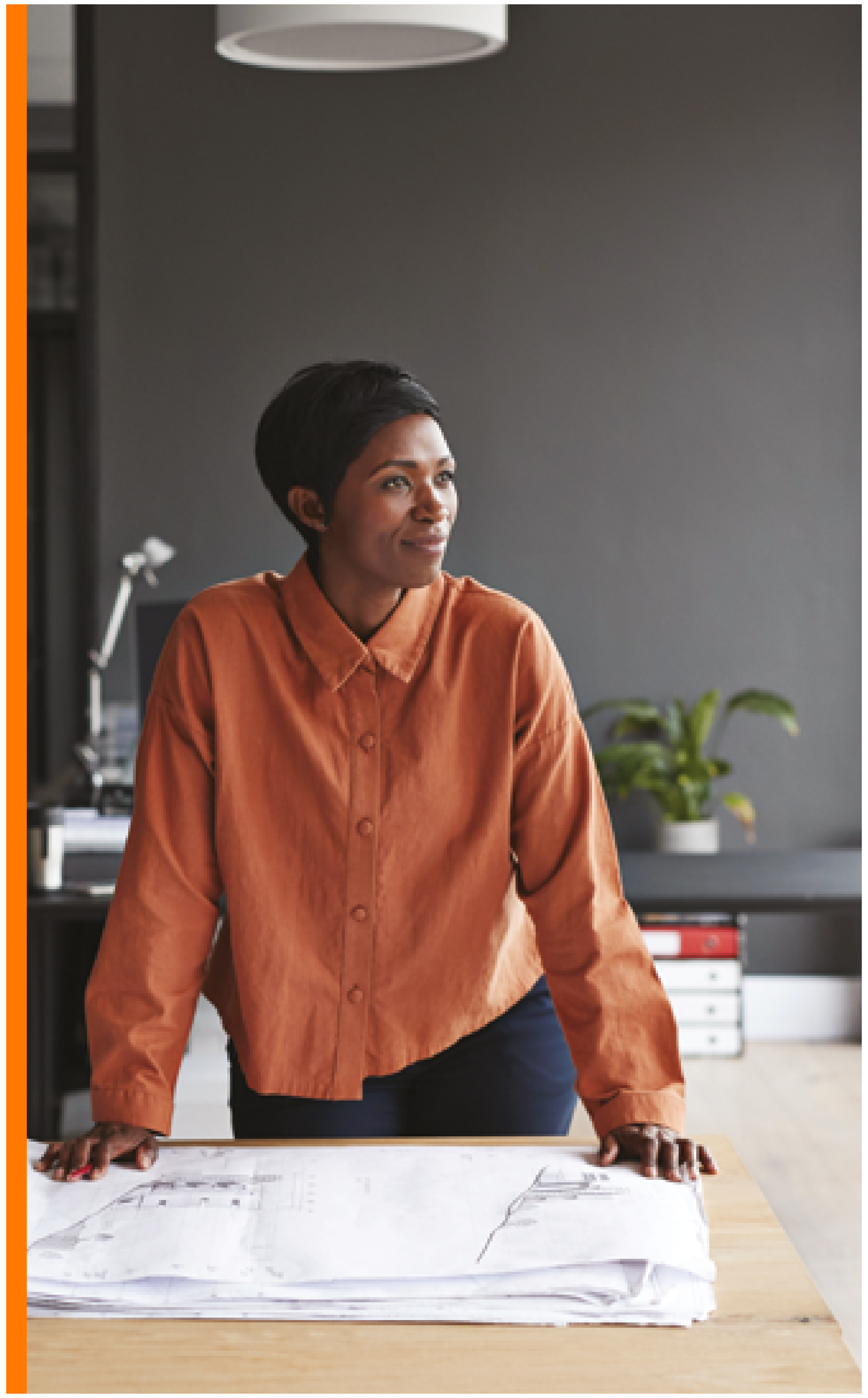
Introduction

With the ambition to prepare for the future, Orange is contributing to the design of the 6th generation of mobile communication, what we refer to as 6G. Orange is actively involved in several 6G collaborative research projects and leading initiatives, including the European flagship Hexa-X project [1], the NGMN Alliance [2], and the IOWN Global Forum [3]. Committed, as a trusted partner, to give everyone the keys to a responsible digital world, we think it is our role to provide inspiration and vision, as well as an informed explanation about this future technology currently in the making.

This White Paper therefore discusses Orange's vision for 6G, selected 6G use cases, and candidate technological advances and solutions for 6G.



1. Why 6G?

Digital communications have become a cornerstone of society in large parts of the world. Along with the digitalization of workspaces, the widespread adoption of working from home and remote education, and the ramp up of telemedicine, wireless mobile communication is becoming even more deeply rooted into our lifestyles and habits, both in the professional and private spheres. The development of mobile communications has followed successive generations, from the first generation of analog systems (more than 3 decades ago) to the fifth generation (5G), currently being deployed.

Mobile communication systems upgrade regularly within a generation to address feedback from operational experience, traffic growth, and evolving security requirements, to name but a few. As such, 2G, 3G, and 4G have continuously evolved since they were launched, with 5G following a similar path. However, roughly every 10 years, the mobile communication ecosystem engages in designing a system from the most up-to-date techniques, potentially revisiting limiting design principles of the current technology.

This periodicity stems from the time needed for research, standardization, international spectrum harmonization, and industrialization: about 10 years from the technical concepts to the commercial launch, as illustrated in figure 1.

For the last few years, "6G" has been presented as the next generation of mobile communication technology, and is already the subject of intense research activities. Although attracting significant media attention, research on 6G is still in its infancy, and studies have only recently started on new usage perspectives and emerging candidate techniques[1]. Indeed, the telecommunications ecosystem is expecting 6G commercial deployments from 2030.

What 6G services, capabilities and networks will look like in 2030 is still an open question, but as for any telecommunications system, 6G will be progressively defined, as consensus will be established within the ecosystem regarding its design objectives and technical solutions. The consensus building phase is currently ongoing through the exchange of ideas and results in research conferences, collaborative projects, and professional organizations. It includes analyses about future services, performances, practical feasibility at affordable cost, added value, and environmental impact.

Designing a communication technology for the 2030s relies on 1) understanding future service needs on the 2030 horizon and beyond, 2) investigating techniques improving performance versus the state of the art, and 3) combining different techniques to build a mobile communication system that addresses the identified needs and constraints. The first two steps generally feed each other: new service requirements stimulate research while increased performance inspires new services. This is where we are currently for 6G.

The third step will start when there will be a sufficient understanding of the target services and technical capabilities to set initial design objectives or requirements, which is expected in 2023. Consensus building will culminate with standardization, which will specify service requirements, architectures, interfaces, and protocols, that should be addressed globally. Indeed, a common global standard will be key to enable affordable costs via economies of scale, interoperability and international roaming. The release date of 6G specifications has not been set yet, but a reasonable assumption is approximately 2028, with standardization starting around 2025.

Orange's goal is to strive for 6G to deliver value to the society in the 2030s, in a secure, resilient, environmentally and economically sustainable way.

Many of the foreseen stakes of the 2030s are already present today, e.g., climate change, the biodiversity crisis, the need for education and healthcare for all, elders care and autonomy, more efficient industry, agriculture, transports and logistics, sustainable energy production and usages, resilience to massive and successive crises, security, privacy, sovereignty and equality.

The associated challenges are expected to increase as the world population will grow, age, gather in larger or denser cities, under more severe climate change impacts.

The digital communication ecosystem is already committed to addresses some of these challenges. However, higher performance communications can provide means to address them more efficiently. In addition, the technological landscape will evolve in various other fields, e.g. health, robotics, transportation, calling for refined mobile communication capabilities.

This White Paper provides an overview of the current 6G development process and proposes a path to deliver on Orange's societal and environmental vision for 6G.

Usages and services leveraging the expected 6G capabilities are under investigation.

Section 2 will introduce some of the main use cases currently identified as valuable by Orange. Requirements derived from foreseeable use cases, as well as operational constraints, play a key role in shaping a technology. An overview of Orange's requirements for 6G is provided in Section 3. Section 4 reviews some of the techniques currently eligible for integration into the future 6G system, with a focus on particular activities that Orange pioneered in order to address environmental sustainability and exposure to Electro-Magnetic Field. Section 5 concludes the paper on the way we should build 6G by involving future users and all the stakeholders.

[1] In fact, we can date the kickoff of the 6G worldwide effort to the 1st 6G Summit, in April 2019, in Levi, Finland.

“2G, 3G, and 4G mobile communication systems have continuously evolved since they were launched, with 5G following a similar path.”

	Research on enablers	System research	Development: Standardization	Development: Trials	Launches
6G expected timeline	2014: Reconfigurable Intelligent Surfaces concept	2021: launch first European research projects (Hexa-X)	2026: launch technical studies	2028: first specifications	2030: launch
5G	2007: massive MIMO concept	2012: launch first European research projects (METIS-2020)	2016: launch technical studies	2018: first specifications	2020: launch in France
4G	1988: coded OFDM concept	2004: launch first European research projects (WINNER)	2005: launch technical studies	2008: first specifications	2012: launch in France
3G	1989: CDMA for cellular communications	1989: launch first European research program (RACE)	1991: start of ETSI activities 1998: foundation of 3GPP	1999: first specifications	2004: launch in France
2G	1958: MSK digital modulation	1982: launch of MARATHON project in France	1982: launch technical studies	1987: first specifications	1992: launch in France

Figure 1: Development of a mobile network technology

“6G is currently in an early research phase, with commercial deployments expected from 2030.”

2. Selected 6G Use Cases

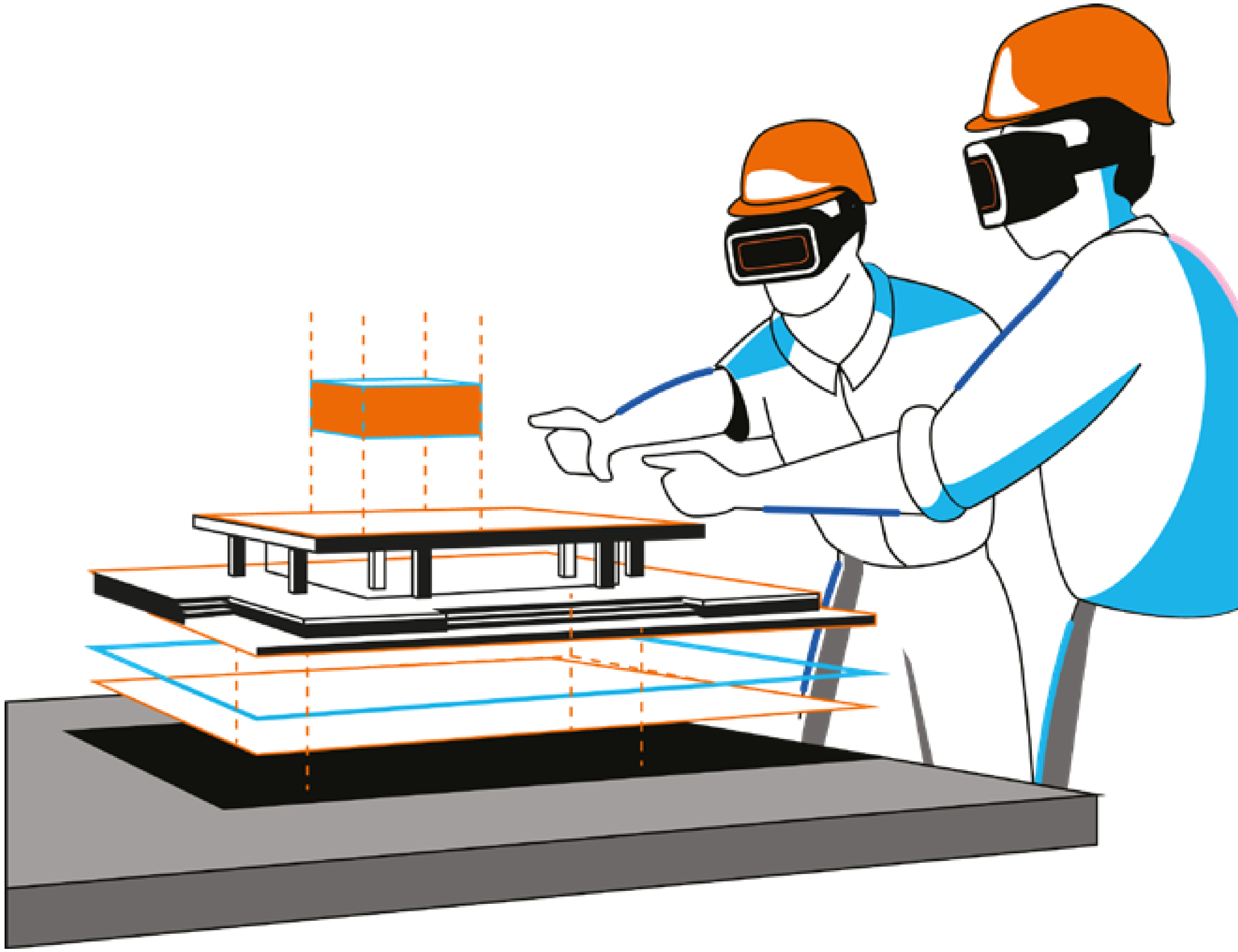
Since the early discussions on 6G, various organizations and projects have been working on the identification of iconic use cases. The Finnish 6G Flagship research program [4] pioneered this work with a White Paper [5], that identified a first set of use cases considering the various device types expected by the time of 6G commercialization.

Different companies then released their own White Papers, presenting their vision, foreseen use cases, and requirements for 6G. Collaborative European projects also started in early 2021 within the European H2020 framework [6].

Among these 6G projects, the Hexa-X flagship [1] aims to develop a 6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds. One of the first Hexa-X deliverables identifies a comprehensive set of use cases [7]. Other organizations such as NGMN are also working on use cases. NGMN produced in 2021 a White Paper that presents the operators' vision and envisaged drivers for 6G [8] and in February 2022 a White Paper that focusses on use cases [9].

At Orange, we think 6G needs to enable services that bring value to society and address future societal and environmental stakes, as initially introduced in [10]. In particular, in addition to optimizing its own carbon footprint, 6G can contribute to the transformation of the economy towards reduced carbon emissions as required by the Paris Agreement to limit the global warming. Indeed, 6G can help reducing the environmental impact of various sectors (e.g., transportation, industry) by enabling new services to optimize their energy consumption, and natural resource usage.
Other examples of 6G value for people and society include reduced inequalities for access to education and healthcare, more efficient industries and agriculture, and safer transportation. 6G is thus recognized as a means of achieving some of the 17 United Nations Sustainable Development Goals (SDGs), like SDG #9 that aims to "build resilient infrastructure, promote sustainable industrialization, and foster innovation."

A subset of promising 6G use cases that Orange believe will benefit people and the planet is described below, as an illustration of the potential of 6G. Many more new services and usages are likely to emerge in the future. The use cases currently identified need to be further analyzed in terms of technical feasibility, market relevance, and economic and environmental sustainability to become real services in the 6G era.



"6G can help reducing the environmental impact of various sectors (e.g., transportation, industry) by enabling new services to optimize their energy consumption, and natural resource usage."

Immersive experience

The pandemic has boosted the use of video communication, turning it into a key tool for work and education, but also an access means to various services such as health, culture, sports, etc. 5G is about to introduce and generalize Augmented Reality (AR), Virtual Reality (VR), and eXtended Reality (XR). With 6G, the experience should become fully immersive, so that remote users connected through a videoconferencing facility could behave and work as if they were in the same room. This immersive experience will be possible thanks to the transmission of advanced high-quality video such as volumetric video, and the combination of actual and virtual elements to improve collaboration between people.

The communication of additional senses, such as touch, is also considered to facilitate interaction. This fully immersive experience is an enabler of Metaverse, alongside another enablers (such as Artificial Intelligence, Blockchain or Digital Twins).

At Orange we do believe that immersive experience has a strong potential to bring value to people and society, particularly through the avoidance of unnecessary transportation, but also through the improvement of remote teaching and learning facilities, enhanced remote medicine, a wider access to culture (e.g., immersive visits to museums, remote participation in cultural events with the sensation of being on stage with the artists), new artistic creations, or a new dimension to entertainment. Besides enhancing the immersive user experience, 6G should lower the cost of providing such services and therefore democratize their access.

Digital twins

A Digital twin is a digital replica of a physical object or any other entity, like a network. 5G capabilities can facilitate the collection of data required to maintain the synchronization of a digital twin with the entity it mirrors. 6G should enable the development and generalization of digital twins, thanks to increased capabilities that can help maintain an accurate image of complex systems. 6G techniques should also be able to provide real-time (or near real-time) synchronization between a physical entity and its digital representation.

Digital twins can be a tool to manage assets, such as complex machinery, and flows of objects and people in various applications, like smart cities, smart buildings, or smart agriculture. Indeed, beyond assistance through digital visualization, digital twins allow to run various algorithms, including AI, on the digital representations. This can be for instance to predict how a system will evolve in the future, or to test several solutions in the digital space before applying them in the real word.

Digital twins can significantly contribute to the preservation of the environment; the digital representation can be used to reduce waste in cities, or optimize the routes for logistics to minimize energy consumption. Digital twins can also bring value to society and people by exploiting the information provided by digital maps of various environments for the sake of people's welfare; digital twins can indeed help prevent accidents or monitor the environment to predict natural hazards. The full scope of services and applications to exploit this concept is yet to be determined.

Robots and autonomous systems

Robotics and autonomous systems, such as drones, in industrial plants and beyond represent a prominent class of 5G use cases. Thanks to enhanced reliability and reduced latency, 5G covers both consumer and vertical sector markets, thereby becoming a viable solution to connect machines with tight service constraints. 6G is expected to confirm this trend and to enable a change of scale in order to handle traffic growth and an increased number of devices and machines, as well as tackle the resulting increase in complexity and the number of simultaneous constraints.

Further reduced latency may be needed to ease the coexistence of robots and human workers sharing the same space (the so-called cobots). Better communication with and between robots also enables easier adaptation of production lines to limited series, reducing failures and also energy and material wastage. Robots can also substitute humans to perform dangerous tasks.

Usage of robots may be generalized beyond the industrial area, with an increasing presence at home and in everyday life, beyond the current usages of lawn mowing or vacuum cleaning. This generalization can support usages beneficial for society and the environment. They can improve the well-being of people, e.g., by facilitating the everyday life of people with physical impairment when deployed at home, or contribute to maintain elderly persons at home with robots dedicated to their care.

eHealth

eHealth service deployment can be fostered by 6G, with various applications.

As mentioned with immersive experience, patients who live in areas that lack medical facilities could benefit from remote consultation services with augmented possibilities of remote examination. This obviously requires wide network coverage, including for rural and mountain areas, in an economically feasible manner (see the digital inclusion requirements section, p. 17). In addition, digital twins can be used to mimic the human body through a network of sensors that monitor a set of biometric data in real time, thereby allowing better prediction and prevention of health issues. More detailed information about the health and body of a person will call for high levels of security and privacy.

Use cases are a powerful tool to guide the development of a technology, as they provide an indication of the required performance and capabilities. The next section introduces Orange's vision for 6G requirements.

The most significant work on requirements to date is carried out by the Hexa-X project whose societal values, such as sustainability, trustworthiness, and inclusion, are at the core of the 6G vision. Requirements related to these values have been considered through Key Value Indicators (KVIs), as well as advancing the conventional perspective of technical performance via Key Performance Indicators (KPIs). Hexa-X has established a blueprint for the upcoming technology development, which will help the bottom-up refinement of KPIs and KVIs.

3. Requirements for 6G

6G activities are currently focused on drivers, vision, use cases, and technology enablers. Discussions about requirements remain at an early stage. Requirements are usually derived from a consolidated description of drivers, vision, and use cases, as well as an understanding of the technical possibilities, which is not the case for 6G yet. We believe the 6G requirements work must encompass developing business, operational, environmental, societal, and technical requirements that can be agreed upon by 6G stakeholders.

Different visions for 6G requirements have been expressed in the literature, especially regarding performance requirements.

The latter often proposes performance improvements by one or several orders of magnitude compared to 5G [5, 11, 12, 13, 14]. For instance, throughput values from 100 Gbps to 1 Tbps are considered for holographic-type/immersive communications, and a connection density of 10-100 million devices per km2 for connected machines, among other performance requirements. 6G is indeed expected to reach higher performance than 5G to enable new services and sustain the expected traffic growth, however further work is needed to define the exact requirement values we should aim for.

We believe that the standardization of 6G performance requirements should eventually be driven by the societal and economic value they will enable, and be backed by sufficient market interest. The operational experience gained from the capabilities and requirements recently introduced with 5G networks, such as reliability and latency, will also need to be considered, including adoption and cost of delivery. In general, the enhanced network performance enabled by 6G will need to be accompanied by means to ensure the delivery of this performance with certain levels of quality of service, so that operators can commit on levels of service to their customers. In addition, uplink (from terminal to the network) throughput and capacity will need to be considered with particular attention to meet the expected demand for live user- or machine-generated content, including at scale, e.g. high-quality video streaming in crowded venues.

Orange's societal requirements for 6G

Delivering the services described in Section 2 in an efficient and sustainable way calls for higher network performance, such as higher capacity and data rates, but also additional requirements that are not purely performance oriented. We introduced the latter as societal requirements in [15] as summarized in the figure below.

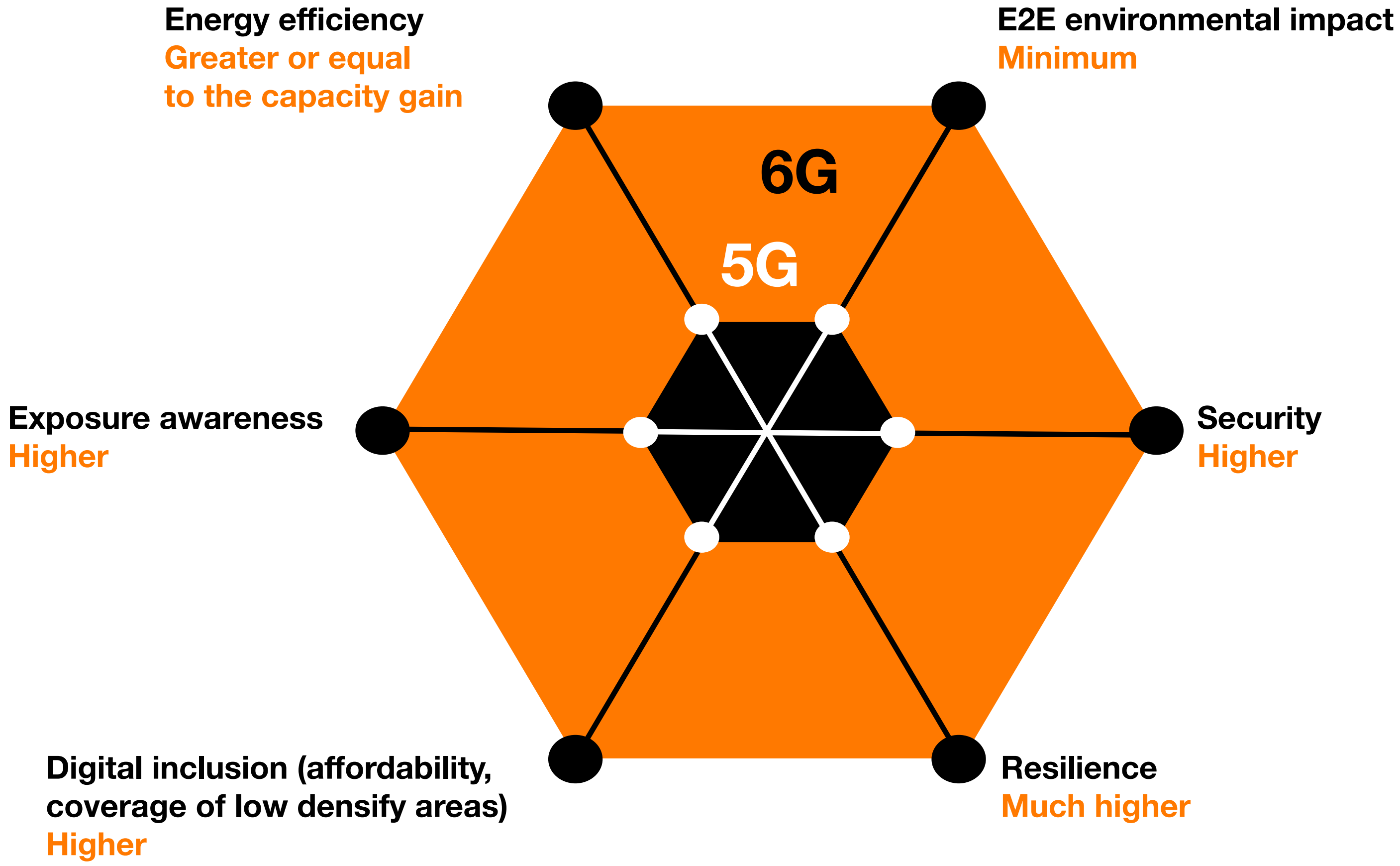


Figure 2: Orange's vision for 6G societal requirements

High energy efficiency

Measurements performed on the Orange networks on 2G, 3G, and 4G have shown that each mature generation of mobile communication technology has reduced the energy required to transmit one bit of information by a factor of 10 compared to the previous generation. Up to 4G, this improvement was obtained by a combination of technical progress, allowing the transmission data rate to increase while keeping power consumption at practically acceptable levels. In 5G design, an explicit focus on energy efficiency was introduced, which led to specifying dedicated solutions to save energy, thereby allowing the energy efficiency gain of 5G to reach the factor 10 improvement already by 2025, and a factor of 20 by 2030, according to Orange studies.

As 6G will provide more capacity, its design needs to further decrease the energy consumed per transmitted bit and per covered area. The 6G energy efficiency target should at least match the capacity gain, in order to not increase the overall network energy consumption. But research on architectures and technologies to specifically further reduce energy consumption are required. A promising direction is to address energy efficiency from a holistic design approach across the whole Information and Communication Technology (ICT) chain, involving services design and Internet protocols in addition to networks.

Minimum environmental impact

Beyond the energy consumed during the operation of 6G networks, the overall environmental impact of 6G should be minimized. This includes the abiotic resources (e.g., ore, water) consumed during the manufacturing of network equipment and terminals, as well as the CO2 emitted during their lifetime from manufacturing to end of life.

Directions to address this requirement include extending infrastructure sharing, extending the hardware usage time through improved reparability, modularity and upgradability, and recycling efficiency. New connectivity techniques reusing existing radiowaves instead of transmitting new ones can also reduce the amount of materials needed to build equipment, as will be introduced in section 4.
6G is the first system having the overall environmental impact taken into account from the initial research and design phases.

High resilience, security, and privacy

Resilience, data security, and privacy have been major design objectives for all mobile communication systems. As the role of telecommunications becomes more and more critical for daily activities, work, education, health, public services, and industries, the importance of these stakes rises accordingly.

The 6G design should therefore provide means to ensure high levels of resilience, security, and privacy for the 6G system. This includes raising the general level of protection, by leveraging recent technical progress, as well as providing solutions to mitigate the potential risk of failure or attacks opened up by the new capabilities and technical solutions that will be introduced in 6G (e.g. fixed and mobile networks convergence, growing role of AI, THz communications). Local network autonomy should be enabled in case of isolation from other parts of the network.

6G also needs to contribute to the development of trustable networking environments despite possibly untrusted multi-party ecosystems, where the service scope spans several domains managed by different, possibly competitive, entities (e.g., a 6G slice service that would serve the needs of a global company.) This implies specific means for guaranteeing service and data availability, security, and privacy across multi-party infrastructures to provide an overall sufficient level of trust for services.

Overall, 6G should facilitate the commitment of network operators to service level agreements specifying levels of quality of service, security, and service availability.

Digital inclusion

As telecommunication technology becomes more and more pervasive to human activities, it is a societal requirement that everyone can access digital services with an appropriate level of quality. Currently, some people cannot access Internet services due to network coverage, know-how or revenue issues.
In the first case, the issue is mainly economic, as poorly covered areas are generally sparsely populated or difficult to access, so the foreseeable revenue from users does not compensate for the network infrastructure cost. This is especially true for rural areas. Providing coverage in these areas requires reducing the cost of network infrastructures per square kilometer of coverage. Possible directions include cheaper radio sites (including equipment, energy, and connectivity to the core network), extending the range of radio sites to minimize their number, accessing to additional low frequency bands, or relying on Non Terrestrial Networks (NTN, see Section 4). 6G should be designed to address these goals.

Experiencing difficulties in accessing the network can also be due to lack of know-how on using a smartphone or a computer. This can be addressed through training, like the training provided by Orange Digital Centers, or through simpler and more intuitive interfaces such as vocal interfaces. The latter is an area for technical research, which is expected to progress significantly in parallel to 6G research.

At last, the cost of the service can also prevent some people to access connectivity. This situation can be addressed with public support or special commercial offers, as the Orange "Coup de Pouce" in France.

Exposure-aware communications

A common solution to expand network capacity is to increase the transmission spectrum, which requires operating additional frequency bands. However, using an additional frequency band increases the power transmitted, and thus the resulting exposure to Electro-Magnetic Fields (EMF). Operators are subject to strict regulation about EMF exposure.

In most countries, national regulators define the EMF limits based upon the guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which have been established from the analysis of scientific results. However, some countries (e.g., Italy, Poland) or cities (e.g., Brussels, Paris) have adopted more constraining limits; sometimes ten times lower than the ICNIRP guidelines.

The EMF exposure induced by current networks is way below the ICNIRP recommended limits. However, the most stringent limits are likely to affect wireless network capacity expansion in the future, at least with the current transmission techniques. In other words, at some point the current systems will not be able to use new frequency bands in areas with the most stringent EMF exposure limits, or at the expense of reducing the transmit power in new bands or legacy bands, thereby reducing coverage. Therefore, the 6G radio design must take this situation into account to become EMF exposure aware, and allow further capacity expansion without significant EMF increase.

Orange advocates the importance of defining societal requirements and including them as one of the initial design criteria for 6G, in addition to "traditional" performance KPIs (data rates, capacity, latency, reliability, connection density, etc.). These societal requirements should be considered with equal importance as performance requirements in the 6G system design.

Orange's operational requirements for 6G

Besides these societal requirements, we also need the future 6G technology to satisfy operational requirements, in order to ensure cost-effective operation of the networks. Note that the above societal requirements of energy efficiency, security, resilience and exposure-awareness can also be regarded as operational requirements.

In general, maintaining affordable network deployment and operation costs is a core requirement to ensure economical sustainability.

Automation of service delivery procedures is critical for operators that provide a large and complex service portfolio in order to optimize the time to deliver a service, reduce the risk of erroneous configuration instructions, manage dynamically-adaptive networks (network topology changes or evolving customer demands, for example) and improve network operation overall.

Automation calls for full-system monitoring capability in order to collect the operation data needed to run automation algorithms.

Trade-offs between different optimization objectives should be able to be configured by the operator, according to service and operational needs. For instance, capacity could be prioritized over low energy consumption in a busy area during the day, whereas at night it would be the opposite.

Flexibility for future evolution, including of the air interface, must be ensured to allow new needs to be supported, that were not foreseen at the time of initial design.

Dynamic enforcement of software upgrades is key to easing the integration of new capabilities without disrupting connectivity services.

"Besides, the environmental impact of equipment manufacturing should be evaluated, including transportation and end of life."

4. Candidate Technical Solutions for 6G

Like each new mobile communication system, 6G will introduce technological innovation to address the challenges associated with the requirements described earlier, and support new innovative usages. In this section, we provide more technical details on key design principles and candidate enablers, identified to meet Orange's 6G requirements.

Key design principles

We discuss hereafter some key design principles and guidelines considered by Orange as particularly relevant for 6G and the associated fixed networks beyond 2030, in line with its 6G vision.

Monitor energy use and evaluate embedded environmental impact

The environmental impact of 6G must be taken into account at all the phases of 6G equipment lifecycle. 6G network equipment should therefore support embedded energy consumption monitoring based on standardized metering architecture and protocols. This will allow network operators to better identify the energy-intensive or underutilized parts of the network and understand their behavior, to optimize and manage them in a more energy-efficient way.

Besides, the environmental impact of equipment manufacturing should be evaluated, including transportation and end of life. In particular, 6G equipment manufacturers will need to systematically provide Life Cycle Inventory (LCI) of the equipment in order to enable operators to have reliable accounts of their indirect impacts.

The outcomes of this evaluation and monitoring could be shared with end-users to foster environment-aware connectivity usages.

Consume zero Watt at zero load

6G should dynamically tailor network energy consumption to the actual network load. When there is no data to transmit, the radio sites should be able to consume almost no energy. This move was already initiated in 5G with the introduction of "Advanced Sleep Modes," which allows radio base station equipment to be turned off for extended time periods when there is no traffic to forward. Improving and extending this principle is required to be able to configure sleep mode periods with more flexibility and granularity.

Rely on hardware and software modularity to extend equipment usage time

Further extending network equipment and device usage time is beneficial to reduce CO2 emissions, reduce electronic wastage, and lower the use of rare materials and resources. To reach this goal, hardware and software modularity are promising ways to improve equipment reparability, and to facilitate the integration of new features.

On the hardware side, manufacturers should provide information on disassembly, spare parts availability, and spare parts distribution, as defined in [16]. Beyond reparability, this will also facilitate equipment recycling.

On the software side, network design should target more modularity, and move to a design based on elementary micro-services that could be used in a cloud native, "as a service" fashion to instantiate network functions. To keep on improving modularity and upgradeability, loose coupling should accompany this design, to break the dependencies on predefined service intentions, which could otherwise prevent evolution or replacement of a given functional block.

Extend and strengthen resource sharing

Network resource and infrastructure sharing between different operators should be improved to better accommodate traffic growth and capacity needs without multiplying equipment, thereby saving on energy and design costs. The 6G architecture and design should therefore natively facilitate multi-operator sharing and allow a service operator to manage the quality of the service delivered through a shared infrastructure

Integrate all access network types to fully benefit from their capabilities

Functional convergence and integration of terrestrial wireless, wireline, and non-terrestrial (e.g., satellite) networks in a unique multi-access network should offer affordable coverage and optimized energy consumption everywhere, at any given time.

This will increase resilience through diversity of air/wireline interfaces, and take advantage of multi-interfaced devices connecting to the core network. Multi-access integration includes possible automatic offloads and seamless connectivity between cellular networks and fixed, Wi-Fi, and fiber networks, depending on capacity needs and energy consumption considerations according to an "always best connected" and "energy-aware" approach.

Design 6G as Trustable Networks

More than security, trust will be a key design aspect of 6G. It should leverage contextualization, confidential computing, and secure elements to deliver security on demand. Security KPIs and Security & Privacy Level Agreements are pivotal to help qualify and quantify trust and assess the needed assurance level. Such KPI should be for example ability to prove isolation inside a network slice and between slices.

Customers should be able to verify at all times the security status of their 6G-based connectivity services. Also, as AI is expected to provide a more efficient decision-making process during network operation, it may also introduce vulnerabilities or privacy concerns regarding the AI model or its implementation. Therefore, there is a need to provide proper supervision by a human operator and by specific rules, or by binding AI action to some kind of "authorized space." with regards to safety, ethical and explainability concerns.

Design 6G as cloud native

The transformation of networks towards the introduction of software technologies (virtualization in particular) should be fostered by 6G. Information Technology (IT) is indeed instrumental in the introduction of network automation techniques, from service order management to service fulfillment and assurance.
This includes the necessary interaction between networks, cloud, and IT infrastructures for the consistent delivery and management of connectivity services. Cloud-based approaches will provide means for increased resilience to 6G networks and will facilitate service delivery on demand by means of open Application Programming Interfaces (APIs).

Network cloudification, as well as edge computing and network disaggregation, will be introduced to 5G as major disruptions in the way we deploy and operate networks. As 6G will build on these disruptions, the 6G development should capitalize on the lessons learned from their field operation in the 5G era.

Design 6G as AI centric

AI-assisted network operation is expected to enable full automation of service delivery procedures, with an optimized resource usage, in a responsive way. Proper AI operation needs specific architectures and procedures to gather the relevant operational data, in sufficient amounts.

AI is expected to provide performance and/or efficiency at all stages of 6G network operations, even for signal processing at the physical layer. Efficient radio communication requires complex signal processing to mitigate interferences and radio propagation impairments, thereby enabling the best possible use of the radio resources. AI and Machine Learning technologies are being studied as part of 6G research to further improve the signal processing efficiency of network infrastructure and terminals. AI could enable better performance through joint optimization in a single processing of complex tasks, today optimized separately, while the processing efficiency of AI-specialized hardware could increase the energy efficiency of 6G terminals and equipment.

Machine Learning at the physical layer could ultimately discover radio channel characteristics and learn how to communicate over it in the most efficient way, thereby defining the air interface (e.g., modulation and channel coding schemes). The practical feasibility of such AI-defined air interface is however uncertain today. Optimization of individual complex tasks, such as improved massive MIMO beamforming and beam management, appears more mature and is already a candidate for study in the framework of 5G evolutions.

6G technology enablers

Towards more spectrum; new frequency bands and spectrum sharing

Using more spectrum is the most immediate way to increase the capacity of wireless networks. Further efforts to identify new or reusable frequency bands below 6 GHz remain a priority to improve the experience of mobile broadband in a cost-efficient manner, especially in low-density areas to facilitate digital inclusion. However, the scarcity of spectrum below 6 GHz requires other means to significantly increase the amount of accessible spectrum.

Part of the answer might be found in new spectrum allocations in the bands between 100 GHz and 300 GHz. Using the so-called sub-terahertz (sub-THz) spectrum, or even THz spectrum, has been identified as one of the main candidate innovations for 6G. The main advantage of these bands is the wide spectral availability (up to several GHz), allowing very high capacity and throughputs of several Gbit/s. However, such throughput is expected to only be achievable over limited ranges and in line of sight between transmitters and receivers. These bands can therefore be interesting for specific use cases that involve large amounts of data to be exchanged in specific environments, e.g., ultra-fast download, telepresence.

In the lower bands, which are well-suited for outdoor and urban coverage, there is less room for new spectrum. However, some spectral improvement could still be obtained thanks to network densification whenever needed, and through more advanced multiple antennas (Multiple Input Multiple Output - MIMO) techniques like distributed MIMO [17] and cell-free design [18], or through media overloading [19] (e.g., Non Orthogonal Multiple Access).

Finally, as spectrum resources become increasingly scarcer, another trend may also be considered, namely spectrum sharing for certain use cases. Spectrum bands that are not optimal for nationwide, large scale deployments have the potential to be exploited through other licensing schemes, such as localized allocations. These schemes, combined with the significant quantities of license-free bands, could also be an option for some 6G local deployments, if efficient enough spectrum access and sharing schemes arise.

Radio sensing and imaging

The general idea of radio sensing is to use the radio waves transmitted for communication to detect objects or movements in the surroundings, in a similar fashion to radar.
Such sensing has been studied with Wi-Fi frequency bands for people counting, posture recognition and even heartbeat monitoring, for several years [20].

However, the higher frequency bands and larger bandwidths envisaged for 6G, together with the increase in processing capability, will enable an order of magnitude improvement in sensing resolution, e.g. down to sub-cm range resolution. Examples of applications include road traffic monitoring, gesture recognition for human-machine interface, or even analyzing the chemical composition of the air or objects through spectroscopy [21], but most of the applications are yet to be imagined. Sensing may be implemented on the terminal side, thereby enabling new "handheld" services, or on the network side, leveraging the infrastructure in place for new added-value services by network operators.

Conversely, the data acquired through radio sensing could further improve communication efficiency by providing 6G equipment with contextual information, which will allow further configuration or processing optimization.

More efficient photonic systems

Today, almost all mobile traffic is converted into optical data flows from the antenna to the core network. Photonic systems and devices therefore have a fundamental role to play to support the evolution of connectivity and network functions towards 6G networks.

In order to accommodate the traffic growth required by the envisioned services in the 2030s, we believe that a paradigm shift is required so that energy consumption and carbon footprints can be kept at sustainable levels. Orange is a member of the "Innovative Optical and Wireless Network (IOWN)" Global Forum, which aims to provide such advanced capabilities of low-power consumption and ultra-wide bandwidth through cutting-edge, next generation photonics-based technologies.

Orange has identified the following technical directions for future optical networks which are of specific interest for 6G mobile networks.

Photonic devices will help reduce the overall latency of 6G networks with more photonic integration, optical bypasses, and coordinated optical switching functions, in addition to strongly reducing energy consumption.

Cloud technologies, SDN architectures, and network function virtualization must be supported, together with optical hardware evolution, to avoid the multiplication of devices while ensuring high network reliability with backup systems and optical link redundancy designs.

Multi-core and hollow core fibers could be a major technological breakthrough in the coming years. Some hollow core fibers have recently shown performances that could significantly increase data transfer rates per fiber [22]. The development of these new fibers should be explored for ultra-low latency optical networks.

Satellite & High-Altitude Platforms (HAPs)

Recent advances in satellite design and launching techniques have significantly cut the cost of the deployment of (very) low-Earth orbit satellite constellations, while advanced electronics and antenna capabilities have allowed a significant throughput progress per satellite. Satellites, together with High-Altitude Platforms that include various types of airships operating in the stratosphere, are studied as candidate cost-effective solutions to deliver connectivity over large areas to standard devices (smartphones, sensors). If cost and performance are confirmed, satellites and/or HAPs would be a major contributor to digital inclusion. Furthermore, thanks to their large coverage and ability to steer beams over traffic demand, satellite or HAP-based networks could be particularly relevant to improving the overall 6G communication resilience and service continuity, by assisting the terrestrial segments wherever and whenever additional coverage is needed.

However, besides the air interface and network architecture adaptation that will be addressed by the telecommunication industry, one must not overlook that embedding a mobile network infrastructure into a satellite or a HAP remains challenging due to the need to cope with specific constraints of such deployment environments (e.g. tight energy constraints, weather conditions).

Furthermore, the issue of spectrum coexistence remains a salient challenge. The traditional identification, study and allocation (e.g., at the ITU level) for each system utilizing frequency bands with certain characteristics may be complemented by approaches that overcome the limited nature of spectrum resources. An example may be the development of flexible spectrum sharing techniques that maintain adequate isolation among different communications while ensuring reasonable spectrum licensing costs.

Satellite and HAPs are already considered for 5G and even 4G direct access, and may be used commercially before 2030. In 6G, they would be natively integrated in the system design, thereby unifying the aerial and terrestrial components in a single system. This would enable service continuity between the two access types with fine geographical granularity, allowing for instance satellite to fill in small terrestrial coverage holes.

Reconfigurable Intelligent Surfaces (RIS)

Orange is currently investigating two candidate enablers to provide wireless connectivity with reduced environmental impact and controlled EMF exposure: Reconfigurable Intelligent Surfaces (RIS) and Zero-Energy Devices.

A RIS is a new type of node in the network that is "passive" in the sense that it does not generate any additional radio waves [23]. When it is illuminated by an impinging radio wave, the RIS radiates back this wave. In our view, the RIS and the reflection it induces must remain under the control of the network. With this in mind, one application is particularly interesting for a network operator, namely a RIS which reflects the incident wave into a desired direction, as illustrated in Figure 3. By controlling such intelligent "mirrors", an operator can shape the wireless propagation to create "reconfigurable, intelligent, and sustainable wireless environments", as described in [24]. We have thus demonstrated that such surfaces can assist antenna beamforming to augment the data rate to the target device, and to lower EMF exposure around the antenna at the same time [25].

RIS are candidate solutions to improve the coverage and data rates in both indoor and outdoor environments without transmitting additional radio waves. In addition, RIS have the potential to enable a lower cost and energy consumption compared to deploying complementary access points. The potential applications of RIS, their design methods as well as cost and energy consumption evaluations are still at the research stage. The main research challenges today are the reflection performance of the RIS, the energy efficiency, the cost and the control of the RIS and, finally, the coexistence between RIS operators.

With regards to the first aspect, Orange has developed its first prototype of RIS (Figure 4), which is remarkably precise as the phase of the reflection can be controlled continuously instead of discretely, contrary to most current solutions [26]. Regarding the other aspects, Orange is actively investigating solutions, and a field trial with Orange partners should be set up in the coming months/years within the context of the European project RISE-6G (2022-2024) [27].

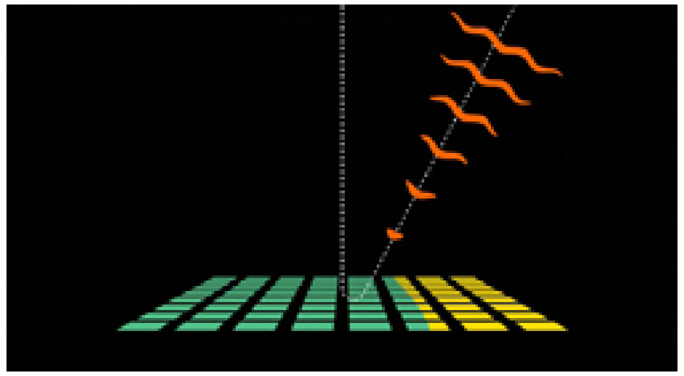


Figure 3: Intelligent reflection concept

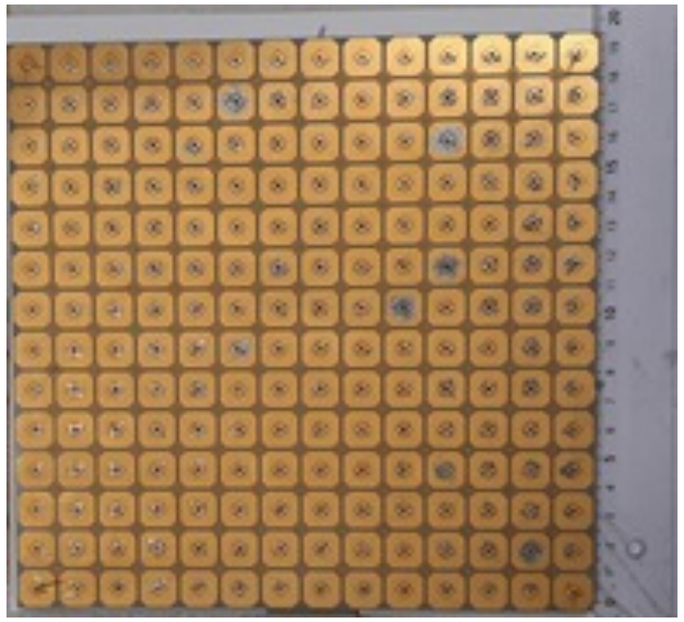
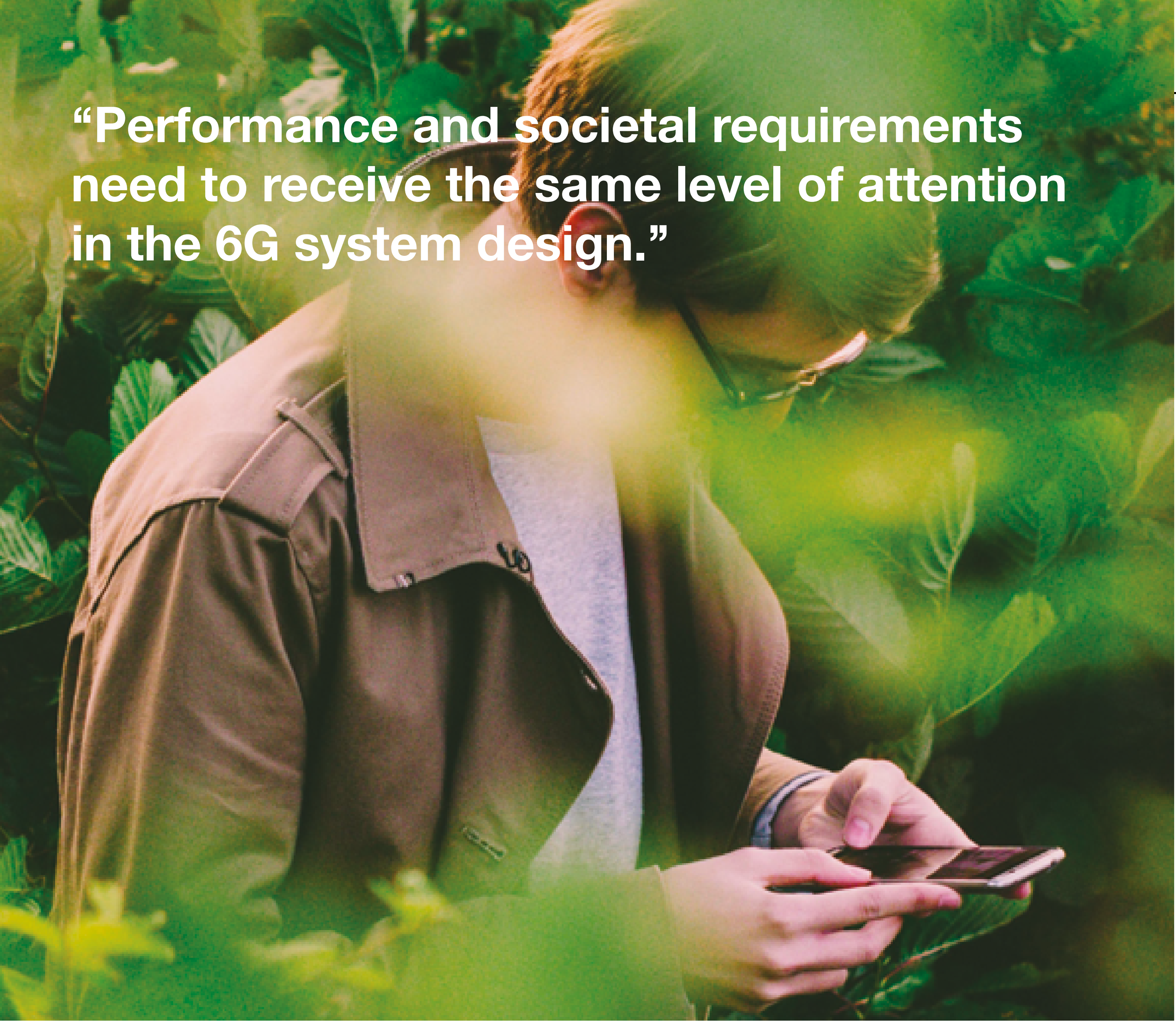


Figure 4: Orange's first RIS prototype



“Performance and societal requirements need to receive the same level of attention in the 6G system design.”

Zero-Energy Devices

Let us now introduce a new type of device that is autonomous in energy, hence its name of Zero-Energy Device (ZED) [28]. Like a RIS, a ZED is “passive” in the sense that it does not generate any additional radio wave. A ZED reflects in all directions, or backscatters, ambient waves to communicate, while slightly modulating the backscattered signal with a message. As such, a ZED does not need a power amplifier and therefore requires little power to operate; so low that it can use renewable energy sources like solar panels.

A ZED is crowd-detectable, as it can be detected by all the surrounding devices and network base stations of one operator. A terminal connected to the network, typically a smartphone, could simultaneously demodulate the signals from a base station and the message from a ZED. Conversely, when a ZED is illuminated by a wave generated by a terminal, it backscatters this wave. A base station connected to the terminal could simultaneously demodulate the signals from the terminal and the message from the ZED.

A crowd-detectable ZED is similar to an RFID tag. However, contrary to an RFID tag, it does not require the deployment of RFID handheld or portal readers, or the generation of RFID reading signals. The crowd-detectable ZED only needs to be close to a terminal connected to the network.

ZED devices would thus contribute to 6G sustainability by enabling the deployment of connected objects not requiring any power charging, and saving on building material (e.g., no power amplifier, small battery), in particular for IoT services. However, the potential applications of ZEDs, and the design of solutions remain at a research stage. We presented a first use case at the 2021 Mobile World Congress; the concept of “asset tracking out of thin air” [29], where signals identifying crowd-detectable ZEDs are tracked without additional waves, energy, or equipment. We also demonstrated the first prototypes of crowd-detectable ZEDs. These prototypes backscatter ambient TV, 4G, or 5G waves to communicate, and they harvest solar energy to power themselves. Orange is actively investigating solutions to remaining challenges while preparing future field trials with Hexa-X project partners.

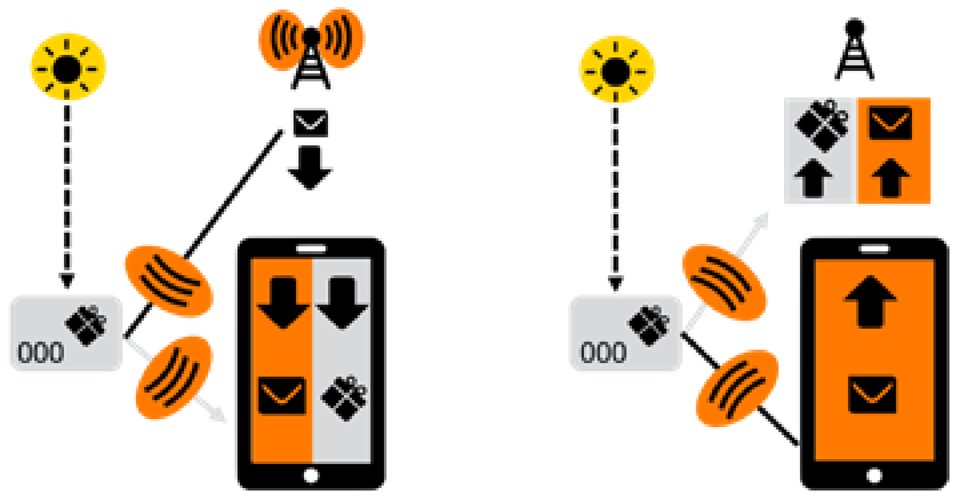
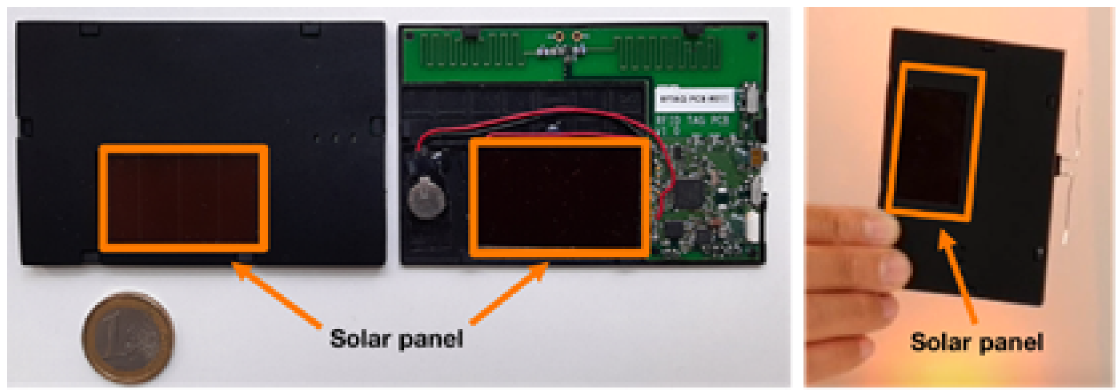


Figure 5: Crowd-detectable Zero- Energy Device (ZED) concept



a) Solar tags backscattering TV and 4G **b) Solar tag backscattering 5G**

Figure 6: Orange’s first prototypes of crowd-detectable ZEDs

5. Takeaways

6G is currently the subject of an intense international research effort, with the aim of a commercial deployment from 2030 onwards. Given the impact of telecommunication in shaping society, the current 6G development contributes to defining the future digital society.

A 6G that provides value to society

Orange's goal is to strive for 6G to provide value to society in the 2030s, in a secure, resilient, environmentally and economically sustainable way. Among the different ways to provide value, contributing to the transformation of the economy towards a significantly reduced carbon footprint and natural ressource consumption is a major objective.

Other ways in which 6G would provide value include better access to education and healthcare, more efficient industry and agriculture, safer transportation, and better living conditions overall.

Orange is active in various leading 6G initiatives where we share our vision and contribute to the research and development of technical solutions to help realizing that vision[2].

A 6G equally based on societal and operational requirements

6G like any future ICT technology needs to address performance requirements in order to cope with the traffic growth and data rate, reliability, and latency demands from future applications. But it also needs to satisfy societal requirements, such as minimizing its energy consumption, overall environmental impact including CO2 emissions, and enabling digital inclusion, high security and resilience, as well as low EMF exposure.

Performance and societal requirements need to receive the same level of attention in the 6G system design. A dedicated research effort is required to elaborate on these societal requirements and to investigate methods to evaluate them.

A 6G made for society, with society

As research is progressing in parallel on use cases, requirements and candidate technical solutions, it is important that the telecommunications research community engage in a dialogue with future users and stakeholders to inform them about the novel and expected 6G service opportunities, and to collect their feedback, ideas, and needs. This dialogue will be instrumental in guiding the development of 6G technology, while ensuring the market and societal relevance of its service offer.

In addition, this dialogue is needed for society to harness the maximum value from 6G; for instance, designing 6G to be efficient in assisting with reducing the carbon emissions of a particular vertical sector requires inputs from this sector about how it will evolve in the years 2030 to 2040, and the associated communication service needs. Gathering enough early evidence of interest for future services and related technology will be important before engaging 6G standardization. As initial standards discussions are expected to start in 2025, this societal dialogue should start soon.

Further work is required to develop the relevant framework and methodology to make sure that 6G designers properly and efficiently collaborate with representatives from the society at large, including citizens, industries, public services and regulators. We hope that this White Paper will be a step in that direction.

[2]These initiatives include the European flagship Hexa-X project and 3 other ICT-52 projects funded by the European Commission (RISE-6G, MARSAL, DEDICAT-6G), the NGMN Alliance, and the IOWN Global Forum. Orange is also active in the 6G-IA Association [30], which represents the European research ecosystem in the Smart Networks and Services Joint Undertaking [31], the European framework for collaborative research on 5G evolutions and 6G in the 2021-2027 timeframe.

"It is important that the telecommunications research community engage in a dialogue with future users and stakeholders"

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