6G AND SATELLITES: INTELLIGENT CONNECTIVITY FOR A SUSTAINABLE FUTURE

→ THE EUROPEAN SPACE AGENCY

ESA LEADING SATELLITE FOR 6G: VISION STATEMENT

ESA is ready for 6G. Through its programme of Advanced Research in Telecommunication Systems (ARTES 4.0) and the Space for 5G and 6G Strategic Programme Line, ESA will guide and support its industrial partners in the development of new 6G satellite technologies, and of applications and solutions that utilise 6G connectivity.

ESA seeks to unify the architectures of terrestrial and non-terrestrial networks, to provide ubiquitous, seamless, versatile, resilient and sustainable connectivity.

TABLE OF CONTENTS

Continued...


5G
6G

1. INTRODUCTION

We've all experienced the frustration of a lost connection. Whether standing in the middle of the Champs-Élysées in Paris or a quintessentially English village in the Cotswolds, we hold our devices up to the sky, arms outstretched, watching intently for the signal to beam down to our mobile phones. Once connected, we are the arbiters of our own communicative world. We can send messages to friends, check directions to the nearest restaurant, or even make a 3D scan of the environment to share when we get home.

But what if we had a connection so ubiquitous that we never would have to worry about losing it? A reliable connection so secure we could share any of our 3D scans in real time? Our family could even join us from another country via virtual reality. What if they could feel the stone walls of the Cotswold villages with you, and sit next to you in a digital twin of the restaurant?

The proliferation of sustainable autonomous transport would allow for the efficient movement of people while distributed connected sensors help monitor and protect the environment. Medical appointments wouldn't have to be rescheduled due to holidays, because doctors could take all vitals from a readily available and wearable device. At last, the digitalisation of industry will be realised through the proliferation of 5G networks and the internet of intelligent things that is always-on and connected worldwide.

With ESA spearheading the world's first satellite-connected world using 5G and 6G technology, the sustainable future of data connectivity is on its way.

2. SATELLITES AND 5G

2.1. WHY 5G?

The advent of 5G and 6G technology will support the next revolutionary steps for humanity on Earth, the Moon, Mars, and beyond. The economic impact of 5G and 6G is expected to result in an annual global benefit worth up to $13.2 trillion by 2035 (source: IHS Markit, 2019), and approximately 5% of all global real output in that year. New connectivity networks are being designed with the future in mind; environmentally sustainable and capable of achieving climate neutrality and supporting the circular economy. Satellites are an important part of these networks, guaranteeing connectivity in a ubiquitous, secure, and resilient fashion. These integrated networks will provide the connective fabric to support the digitalisation of industry and society. ESA continues to support its current and future industry partners to develop the future of seamless connectivity for the world.

2.2. WHAT IS 5G?

5G is the fifth-generation technology standard for mobile networks. The integration of satellites in 5G interconnects the terrestrial cellular networks of phones and signal towers with satellites orbiting around Earth. 5G is designed to provide robust and ubiquitous communication connectivity of people, objects and devices.

2.3. THE ELEMENTS OF 5G

5G is transforming industry and society, thanks to its ability to provide high speeds (enhanced Mobile BroadBand – eMBB), support many connected devices (massive Machine to Machine Type Communications – mMMTC) and offer ultra-reliable low latency connectivity (Ultra Reliable low-Latency Communications – URLCC) (see Figure 1).

Figure 1: The Elements of 5G

Let's review some of the core features promised by 5G and their associated challenges.

Bandwidth: 5G promises to provide very high capacity bandwidth for each individual user. This is likely to result in an unprecedented bandwidth requirement imposed on 5G networks, both terrestrial and their satellite assistants in orbit. In order to mitigate these challenges, careful network planning will be required to satisfy different users and use cases over the same 5G network.

Massive Numbers of Connected Devices: 5G is designed to accommodate a myriad of connected devices forming the Internet of Things (IoT). This can be anything from a smart phone to a temperature sensor in an office building. Our world is comprised of IoT devices, and with each passing day, we will only see more of these devices at home and in the workplace.

Mobility: As different users and use cases rely on connectivity everywhere, 5G will have to accommodate a wide range of mobility use cases and provide the security and continuity required to support them. Whether the user is on land, sea or air, the 5G network must follow; the same is true for planes, trains and ships.

Broadcast: Many use cases will necessitate broadcasting the same information to a variety of geographically-dispersed users at the same time. Optimising content delivery for these cases is important to minimise any network strain. Satellites can deliver rich multimedia content across multiple sites simultaneously and efficiently, using broadcast/multicast streams with an information-centric network and content caching for local distribution.

Security: With end-to-end security being one of the promises of 5G, it's no surprise that widespread adoption has been accelerated across the globe. Preventing improper access to user data—no matter the content—is a foundation of 5G protocols and instrumental in substantiating the data security promised by 5G.

Reactiveness (Low Latency): Some of the 5G use cases (such as haptic and tactile internet-enabled telesurgery) demand very high reactiveness and low latency connectivity. The 5G network will need to implement mechanisms to minimise network delay and distribute information towards the edge of the network to optimise response time.

Ubiquity: Public demand dictates that 5G be available in rural and remote areas as well as in city centres. This is challenging, given the relatively low coverage range of individual 5G base stations and the slow deployments of terrestrial 5G networks, which inevitably prioritise city centres. For the promise of ubiquity to be realised, satellite telecommunication networks will be needed to complement 5G terrestrial coverage, providing high-speed capacity across the globe.

5G networks must operate seamlessly across a set of heterogeneous network elements, with satellites playing a critical role. Network convergence is the key to a future in which new players emerge (such as virtual network operators), pooling terrestrial and satellite services in different domains and use cases. Innovation and novel service developments will benefit from this integration of satellite and terrestrial service required by each service domain.

2.4. THE LAYERED NETWORK ARCHITECTURE

The realisation of 5G's promise for ubiquitous, secure global connectivity requires the seamless integration of multiple radio technologies (terrestrial and non-terrestrial networks). To that end, a three-layer network architecture was designed and implemented:

- The terrestrial layer, comprised of the communications array for fixed and mobile users that uses a number of radio technologies, including 4G, 5G and Wi-Fi;
- The airborne layer, includes high altitude platforms (HAP) and unmanned aerial vehicles (UAV) between 10 and 50 kilometres above Earth;
- The space layer, made up of several different satellite constellations found in highly elliptical orbits (HEO), low Earth orbits (LEO), very low Earth orbits (VLEO), medium Earth orbits (MEO) and geostationary orbit (GEO).

These systems must work in harmony to fulfil the vision of a connected, sustainable 5G architecture and beyond. For example, ESA partner OneWeb and affiliates SatixFy and Celestia, based in the UK, are working to encourage the layered network.

OneWeb's Joey-Sat (named after a baby kangaroo due to the satellite's beam-hopping technology) will be one of the first satellite constellations capable of switching coverage in real time to different parts of the world. This will help manage the demand on connectivity during emergencies and natural disasters, as well as during the day-to-day life of growing and established economies. These industry leaders in the 5G world are realising their goals through the funding provided by ESA's Sunrise Project. Sunrise is designed to enable users to access multimedia content via subscription services over the web or downloaded by satellite.

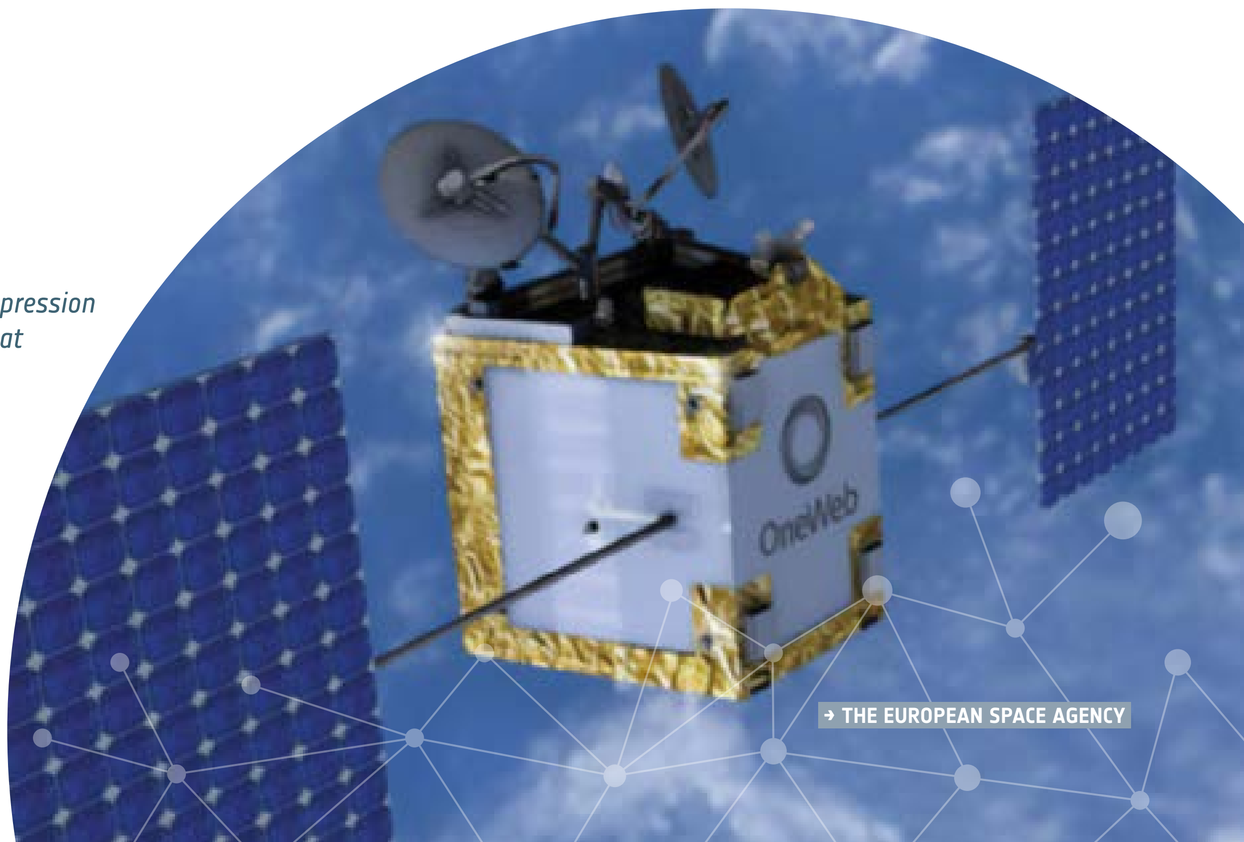


Figure 2: Artist's impression of OneWeb's Joey-Sat

2.5. EXAMPLES OF 5G USE CASES

2.5.1. 5G'S IMPACT ON ENERGY EFFICIENCY

By 2030, batteries are expected to account for 95% of worldwide demand for lithium. The need for long lasting, efficient fuel cells is urgent. 5G will enable artificial intelligence (AI) and hardware to operate in symbiosis to maximise battery output and conservation, thanks to the connectivity provided between machines. Devices will work faster and better than before, using less energy. IoT devices will be capable of operating longer, and autonomous buses and cars will be able to travel farther between charges. The wide coverage capabilities of satellites reduce the need to deploy terrestrial 5G base stations, enabling the development and support of energy efficient solutions, such as the optimisation of energy grid distribution networks and the full use of electric vehicles for manned and unmanned transport systems.

2.5.2. 5G AND MEDICINE

The connection that 5G gives to the medical field is unsurpassed. Doctors and nurses are now capable of responding to patients in remote areas by conducting telemedicine via satellite-enabled video-conferencing platforms. Patient data files, test results and other diagnostic data can be seamlessly transferred from one place to another in seconds. Real time monitoring of patient information (e.g., blood pressure, insulin, heart rate) thanks to low latency advantages of 5G can lead to quicker diagnosis and efficient treatments. Remote areas that struggle with healthcare and access to doctors are now able to reach out to a medic in London, Paris or Frankfurt.

The world's first 5G remote brain surgery was performed in 2019. This patient received a deep brain stimulating implant during the three-hour procedure. The best part about the experimental surgery—besides the fact that it was a success—was the circumstance surrounding it: as neither the doctor nor patient could fly to meet one another, 5G offered an alternative solution. This successful surgery represents the potential to cut costs and broaden access for medical professionals and patients in the near future. The Internet of Medical Things (IoMT) enabled by 5G is seeing the proliferation of connected medical devices, making the capabilities for distant triage and preventive treatment a reality rather than a science fiction dream.

2.5.3. ARTIFICIAL INTELLIGENCE APPLICATIONS FOR EFFICIENCY

AI will play a key role in reducing emissions and network energy costs without impacting the expected performance or experience, according to Nokia. Data transfer accounts for only around 15% of the energy used by a mobile network. As technology and chipsets develop, more and more energy demands are placed on the hardware and cooling fans used to operate our devices each day. It is estimated that 85% of the original energy an IoT device receives is not used productively. AI has the capacity to shut off non-essential systems that are draining energy without impacting performance. This will help cut energy costs by achieving power savings.

2.5.4. TRANSPORT AND LOGISTICS

5G/6G mobile connectivity for maritime, road, rail and aviation can be greatly enhanced by satellite services. With satellites, the coverage is dramatically increased, resulting in unprecedented efficiency in the distribution of data to unlimited amounts of connected devices, enhancing user experience by providing an "always connected" service. This seamless integration of different technologies will be a boon to connected cars, trains and autonomous transport in general. True vehicle-to-infrastructure communication requires uninterrupted coverage and redundancy, which can only be supplied economically with the help of telecommunications satellites.

For the maritime industry, satellite-enhanced 5G/6G will enable cargo transport with autonomous ships, regardless of whether they are in harbour, along coastal areas or in the middle of the ocean.

The digital sky revolution demands a level of connectivity and reliability from aviation in the delivery of related consumer and business services that would not be possible without the reach and capacity of satellites. Satellite telecommunications networks can meet the demands of future airborne services, including drones delivering packages, autonomous air taxis and support to smart airports.

2.5.5. 5G BROADCASTING

Satellite broadcasting has always been an efficient way of delivering media information to large number of users. Thanks to 5G, this can be made even more efficient and integrated with terrestrial systems. The 5G-Emerge project is an ESA Partnership Project led by the European Broadcasting Union with many partners representing both the satellite and online media delivery industries, committed to develop the satellite enabled ecosystem. The project will design, develop and validate a 5G integrated satellite terrestrial end-to-end system and related products addressing satellite (live and on-demand) content delivery services. 5G-Emerge aims to establish a 5G multi-tenant open and modular satellite system optimised for the needs of different industries covering direct-to-home, direct-to-vehicles and direct-to-edge nodes of 5G/6G access networks.

2.6. WHERE WE GO FROM HERE

So far, we've been discussing the advantages of the 5G world we now enjoy and experience daily. Ultrafast connection speeds on our cellphones, laptops and other IoT devices, autonomous cars, buses and drones, state-of-the-art medical solutions for treating patients at home instead of in a hospital, and much more. While 5G continues to offer seamless sustainable connectivity, it isn't going to be enough for what we have on the horizon. Technology is an ever-evolving machine of progress, and ESA is taking steps forward into the future of connectivity for the Earth, Moon, Mars, and beyond.

Just like there was a 2G, 3G, and 4G network before, something must come after the achievement of 5G connectivity. What is the next step? The future is clear: we must continue to innovate in space to serve the evolving connectivity requirements. The future Intelligence of Everything (IofE) will bring with it remarkable applications for AI, virtual and augmented reality, medicine, efficient sustainability, travel to and from the Moon...the list goes on. We are moving on to 6G, our collective vision for the future of communications, and satellites have an ever more important role to play.

3. SATELLITES AND 6G

3.1. WHAT IS 6G?

6G is the sixth-generation technology standard for mobile networks. The integration of satellites with 6G is increasingly important, not only to leverage the successes of 5G integration, but also to increase the contribution that satellites can play in the ever evolving global connectivity requirements. With 6G, the end user can be anything from a person with a device to an autonomous drone, a robot, a heart monitor, an AI security application, and more. 6G will add connective intelligence to the hierarchy of connected people and things. It will offer unrivaled performance characteristics through the creation of the world's largest neural network with integrated sensing, learning, and processing capabilities.

AI will bolster the capabilities of the network, continuously optimising and reconfiguring it for peak performance. The 5G Industry Association has declared 6G to be a "self-contained eco-system of artificial intelligence".

Communications networks will serve as sensors, enabling a better understanding of the physical world and providing a broad range of services.

Moreover, 6G will enhance the existing 5G attributes and fully integrate them with the 6G standard.

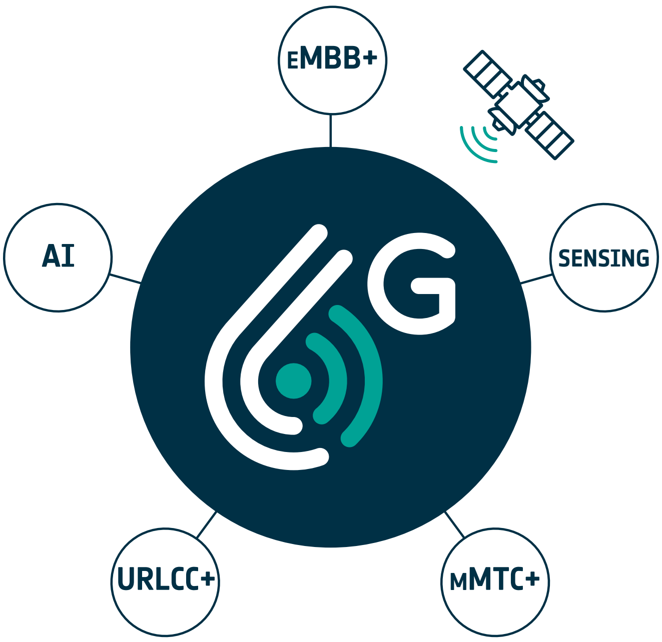


Figure 3: 6G Pentagon

3.2. ESA'S VISION FOR 6G

ESA is ready for 6G. ESA will be the organisation that guides its industrial partners in the development of new 6G satellite technology, and the migration of existing telecommunication applications from 5G to 6G seamlessly, securely, and sustainably. Through its programme of Advanced Research in Telecommunications Systems (ARTES 4.0), ESA seeks to join with like-minded industries working towards the development of satellite technologies and applications that use 6G connectivity, and the orbiting and sub-orbiting platforms that provide them for Europe and the world. ESA will unify the data architectures of terrestrial and non-terrestrial networks, to make satellite connectivity the most versatile and resilient ever imagined.

3.3. ESA LEADING SATELLITES FOR 6G

Thanks to its Space for 5G/6G and Sustainable Connectivity Strategic Programme Line, ESA is providing the means and expertise for its current and future industrial partners to get involved in the 6G revolution. ESA is on course to be the first to launch a 6G-enabling satellite into orbit. If European industry wants to be competitive and at the forefront of 6G development and integration with terrestrial testbeds, then a satellite testbed needs to be in orbit around 2024. In order for integration of satellites to be successful in 6G, terrestrial industry partners must be able to experiment and test in a real environment that can only be provided by a 6G laboratory in space.

This 6G laboratory allows for the R & D process to be realised early in 6G adoption so that Industry can learn and adapt their products to work side by side with terrestrial communication infrastructure. ESA views this laboratory as an open innovation opportunity, where researchers and industry experts can collaborate in space and at home to gain an the understanding of 6G before it arrives.

The Space for 5G/6G and Sustainable Connectivity Strategic Programme Line aims to promote, develop and validate converged hybrid space networks where satellites are fully integrated into the connectivity of telecommunications infrastructure. The programme helps upstream and downstream industry partners benefit the European economy through partnerships that introduce new applications of technology based on 6G. Just as ESA guided the standardisation of 5G for Europe, the agency will continue to lead and support the space industry in developing satellites, space networks, solutions and applications, contributing to successfully achieving the objectives of 6G connectivity.

3.4. CAPABILITIES OF 6G

3.4.1. ARTIFICIAL INTELLIGENCE AND 6G

6G will be the paradigm shift towards using trusted AI learning and operation in daily life. Many organisations promoting 6G and AI together will often identify the native support for AI built-in to the 6G architecture, making AI part of the optimisation process for networks of any size or function.

This Native AI is part of the primary mission of 6G: supporting the sustainable connectivity of AI everywhere. 6G will also feature an End to End (E2E) diagnosis system but this time, supported by AI-based services and applications.

3.4.2. VIRTUAL REALITY, AUGMENTED REALITY, XR AND 6G

XR has become the adopted moniker for all things virtual (e.g.,Virtual Reality, Augmented Reality) and, as such, this section will discuss a variety of virtual applications made possible by satellite connectivity and the advent of 6G.

Immersive 360° XR is an evolution of the current platforms available and will offer resolutions and video frame rates nearly identical to that of human vision. Thanks to 6G's low latency, the preferred user experience required to cross the uncanny valley will become a reality. For example, friends living across the ocean from one another—or even next door—will be able to engage in sports and watch a match together as if they were on the bench, or one of the officials in the game. With the advent of haptic sensors (i.e., the ability to feel and sense objects in real-time in XR scenarios), families and friends will be able to come together and join in the holiday fun and feel that Cotswold stone mentioned earlier, or hug a relative thousands of kilometers away.

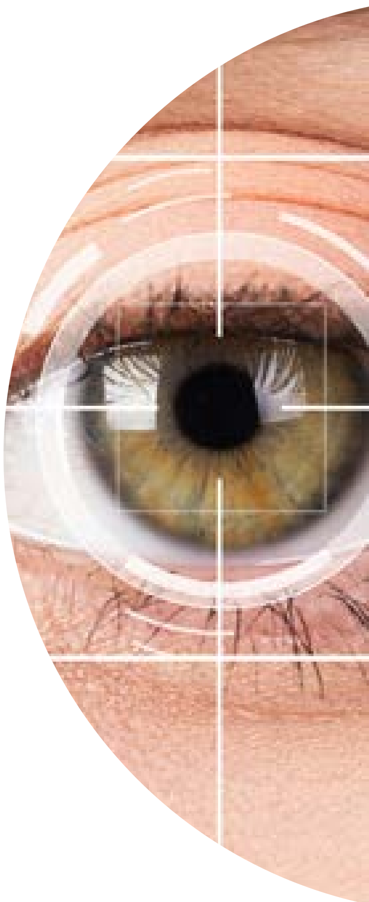
The 6G infrastructure will also enable the development of glasses-free VR and eventually holographic communications. This bleeding-edge technology will come to fruition in the coming years, thanks to 6G. Speeds over 100 Terabit per second (Tbit/s) will provide the basis for holographic surgeries, Earth to Moon troubleshooting, and experimentation. Tele-diagnosis, tele-surgery, and tele-motion control will all become second nature in the evolving economic landscape of 6G. Our planet and its health will improve thanks to holographic conferences and virtual meetings requiring less travel and reducing carbon footprints.

XR-enabled conferences are already a mainstay of our sustainable-minded global community. Members of ESA participated in a celebration of the Convention on Climate Change (COP27) in 2022 through a curated metaverse, designed to bring all ESA sites together across two days. Through VR, ESA's workforce was able to interact and discuss climate matters, attend livestreams and on-site interviews from Sharm-el-Sheikh, and meet-up with friends across ESA. This sustainable form of conference attendance is proof positive that VR is already capable of supporting a sustainable way to work. In the world of 6G, these types of meetings will become common place, thanks to the connective architecture of 6G and the processing speeds offered by edge computing and Machine Learning (ML). Each user will be able to render complex scenes locally and track physical movements with edge-assisted computing, bringing the digital world closer to the physical.

Through Augmented Reality driving will become safer, with XR displays for monitoring traffic, vehicle speeds, weather conditions, and battery health. Augmented Reality interfaces will help impaired community members navigate their way around unassisted by using XR interfaces that project route information, stair count and height, or use haptics and visuals to alert them to nearby obstacles.

3.4.3. INCLUSIVE 6G

Those with physical or mental impairments are often overlooked when new technologies are invented or adopted into daily life. New televisions, brighter smart phones, virtual and augmented reality are not accessible to many of the visually or physically impaired, with many XR interfaces requiring physical dexterity and vision to move around in a digital environment. With 6G, many of these restrictions will be reimagined to deliver inclusive accessibility to technology for all.



XR rigs will now be able to render control interfaces that track eye movement and gestures from available appendages, so family members with disabilities can virtually participate in a "digital vacation" with the family; Controllers requiring arm or hand movement can be calibrated to use eye tracking to determine locomotion in XR experiences. The AI capabilities onboard a 6G satellite can interpolate different user settings for XR environments in real-time, with little to no configuration required for the end user, regardless of limitations.

The visually impaired can utilise over-the-air haptics to feel a piece of meteorite in Germany or shake the virtual hand of the ESA Director General in Paris, France. Haptic technology will provide feedback required for a blind person to interact and participate in the digital world. The future will be for everyone. 6G Satellites will possess the edge computing, AI and Machine Learning capabilities demanded by XR software supporting these use cases for disabled communities. Through 6G connectivity, an entire world of innovation will be readily available to all.

3.4.4. DIGITAL TWINS

The digital twin is a dynamic, virtual copy of any item that looks and behaves identically to its real-world counterpart. Digital twins can collect data from one another to create simulations based on almost any variable. They are used to predict long-term performance of materials to estimate lifespan, such as the jet engines of a commercial aircraft or the lithium-ion batteries of an electric vehicle, and to shakedown prototypes before production. Digital twins enable teams around the word to collaborate, build, test and deploy changes quickly, efficiently and sustainably.

6G will enable new forms of digital twins. Computer-aided design applications will be used to compile and interpolate 3D scans of models taken and transmitted in real time via the signal strength of 6G to the digital twin server of a given industry or organisation for analysis. Low-latency transfer times will enable engineers to produce complex scans and beam them around the world within minutes. Engineers will be able to view and manipulate the digital twin via XR. Substantial data will then be collected and interpreted by advanced AI—either remotely, thanks to 6G, or locally—to meet the needs of the developer or end user.

3.4.5. HUMAN AND PLANETARY HEALTH

In 2016, the United Nations Framework Convention on Climate Change created an ongoing project to highlight the need to focus on human health and planetary health combined.

The premise of "One Health" is that we as humans assess our wellbeing in terms of three key areas:

- The manner in which individuals from all walks of life, rich or poor have to access medical treatment and sustenance,
- How plant and animal life co-exist with us on a daily basis in a sustainable and eco-friendly way towards the achievement of the first goal,
- How we treat our planet and manage our impact on its well-being.

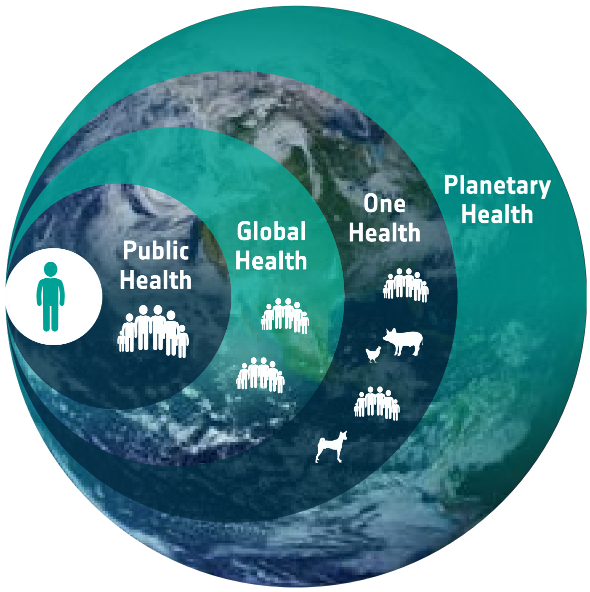


Figure 4: Human and Planetary Health

These behaviours inform the idea of Planetary Health, which is also one of the target areas of satellite and 6G, aiming at improving personal health, while at the same time, safeguarding our planet.

It was once common to think about health in an individualistic way, in that one's absence of illness indicated good health. The concept of public health notes the correlations and connections among people; that people's exposure to environmental contaminants occur in groups, occupational hazards are a feature of how we organise and regulate society, and that the transmission of infectious diseases can be interrupted.

Public health and well-being became a collective enterprise during the 2020 COVID-19 outbreak, changing the way we live and work. Our planet also witnessed the effects of the pandemic, for example, clearer blues of the Canale Grande in Venice, Italy—and thanks to satellite images from ESA, we were able to witness in real-time the positive effects fewer cars and buses had on cities like Paris, Madrid and Rome. Nitrogen dioxide concentrations were dropping on a global scale, and the natural environment benefited. Perhaps Friedrich Schelling, the 18th Century professor, would be proud that humanity finally realised the "secret bond connecting us with nature."

The combination of 6G, satellite, AI and digital twins will significantly contribute towards improving both human and planetary health.

In this "One Health" world we are creating, digital twins will become a "must have" technology. Imagine a kidney transplant patient whose new organ is extremely delicate and subject to illness or rejection being analysed around the clock by a team of nephrologists. These doctors would have already prepared a digital twin of the transplanted kidney available for virtual testing and diagnosis over 6G satellite connection; medical colleagues around the globe could link-up over the 6G network and examine organs virtually. A world-wide network of doctors anticipating treatments and thus prolonging the life of transplanted organs. With synthetic transplant patients—or those with pacemakers, etc.—digital twins are capable of testing software or BIOS patches for patient-specific circumstances before downloading to the patient device itself. The same can be said for IoMT wearables for heart-rate, blood insulin and blood pressure.

3.4.6. NETWORK SENSING AND EDGE COMPUTING

Directing autonomous vehicles or monitoring the prevention of forest fires and floods all demand sensory networks that depend on 6G connectivity. Wireless sensing networks utilise a hive-mind of sensors to aggregate data before sending it for final processing. 6G's AI capabilities combining with low latency high throughput bandwidth can completely change the way in which data is collected and used. Sensor networks built to analyse flooding and drought can collect and process data in real time, reducing the workload on all aspects of the wireless sensing networks.

Edge computing disperses the processing workload to speed up and reduce strain on computer networks. Instead of nodes or wireless sensing networks sending information back to a data-processing centre, the nodes themselves act a processing unit. This enables an autonomous shuttle to operate safely when it encounters moving pedestrians or other obstacles. The processing unit managing traffic data and deciding what the vehicle does next is located directly in the vehicle. This will also enable other vehicles to communicate with each other, acting as a mesh network.

ESA is partnering with industry to bring edge computing and network sensing to the space-terrestrial networks of 6G. Satellites will be adaptable and create a series of multi-edge computing nodes in space. The days of trying to anticipate the future use case for a satellite will be over. The satellites themselves will adapt and learn.

3.4.7. RECONFIGURABLE SURFACES

The reconfigurable intelligent surface is a new enabling candidate wireless technology designed to control the radio signals between a transmitter and a receiver in a dynamic and goal-oriented way, turning the wireless environment into a service. With such a system, an antenna will be capable of receiving and reconfiguring any type of signal—or use case—it may require. Teamed with edge computing and wireless sensing networks, ESA and its partners will be pioneering a new way to develop and define what a telecommunication satellite—or a constellation of satellites—can do for people.

3.4.8. SUSTAINABILITY

Telecommunications satellites can help to address climate change, poverty and inequality, as well as the other UN Sustainable Development Goals for 2030. To be truly sustainable, 6G technologies must be the most energy-efficient devices to aid in the reduction of global dependency on non-renewable energy sources. ESA and its industrial partners will lead the green revolution to restructure how industry fuels the 6G world.

AI applications and network sensing capabilities will monitor air pollution, waste and water quality, shipping on the oceans—and through the use of digital twins—make maintenance of boats and heavy goods vehicles extremely efficient. The advent of carbon neutral data centres that use AI and automation will improve efficiency throughout the entire data supply chain and help take advantage of new energy-conscious components. The use of XR will help reduce the need for flights, cars, and buses.

3.4.9. CONNECTED CARS, CONNECTED EVERYTHING

5G saw the evolution of vehicle-to-vehicle technology in autonomous vehicles and traffic control along the road. 6G provides the capability to make connections between the vehicle and the environment. For this to succeed, ubiquitous connectivity must be in place and this can only be achieved through uniform and resilient satellite and terrestrial networks. The infrastructure must be modified to accommodate vehicle-to-everything technologies – such as AI-based edge computers, network traffic sensors – and upgraded from existing 5G protocols. Vehicle-to-vehicle technology encompassed short-range communication, whereas vehicle-to-everything demands long-range capabilities. By using back-end cloud services, ground stations and mobile networks bolstered by satellite, the vehicle-to-everything landscape can be realised. ESA's industrial partners are already working on projects to take advantage of antennae and terminals designed for vehicle-to-everything (V2X), and will continue to integrate reconfigurable intelligent surface technologies so that satellites can become a reliable extension to the cellular network.

V2X will extend to drone usage and piloting, too. With the advent of drone taxis, delivery services, and dedicated drone shipping lanes in the skies, the need for communication between everything is extremely critical.

Successful implementation of vehicle-to-everything technologies will help monitor traffic lights, speed limitations, congestion, local air pollution levels and drone traffic lanes, and will also protect pedestrians. Some of these capabilities are being tested now in 5G environments, which will ease the maturity of all systems in the 6G architecture and create new use cases built around a world where all aspects of transportation communicate via satellite connectivity.

Figure 5: V2X Communications

3.5. DATA SECURITY AND 6G

6G will offer the security and trustworthiness that many industries are anticipating now from 5G. Data privacy and security are the main concerns. Moving towards the decentralised data storage systems that 6G satellite connectivity can offer will fuel the transformation of the digital world. The encryption capabilities of an always-on, always-learning neural network tied together by 6G will translate into stronger security architecture, more robust defences against distributed denial of service attacks (DDoS), and an integrity that only the ubiquitous connectivity of 6G can provide.

3.6. NEW SPECTRUMS

Mobile communication uses different frequency bands. Just as 5G broke new ground with the utilisation of millimetre wavelengths, 6G will broadcast with higher frequencies beyond the GHz range into THz bands. Because 6G offers higher data rates and ubiquitous connectivity, it requires access to more spectrum. Spectrum sharing and co-existence is important for the mid-band as well as the expansion into high-band.

THz bands can typically accommodate very high data rates over short and middle distances. The use of THz communications over satellite is in its infancy, but needs focused effort in order to safeguard and guarantee the presence of satellite communications at these frequencies. With the ultra-wide bandwidth and shorter wavelength of the THz range come challenges for ESA's 6G industrial partners. The signal degradation due to molecular absorption must be addressed, and new antennae systems must be developed to switch between all spectrums required in the 6G infrastructure.

The demands of 5G applications must also be taken into the spectrum calculation and accounted for in the early stages of 6G adoption. With time, 5G applications will be migrated away from spectrum bandwidth and 6G channels can be allocated to specific channels.

The use of channel modeling before 6G will help engineers to model and predict how the THz bands will react under the stresses of 6G demand and the demanding satellite links. It will also guide the development and roll-out of extra-large aperture arrays and other antennae technology. The protocols for private 5G networks will serve as a model for managing the switching between bands to avoid interference.

3.7. HOW DO WE GET THERE?

6G will be different from any other wireless standard that has come before. Moving from “connected things” to “connected intelligence” requires a lot of infrastructure developments to be in place. Data must be transmitted to and from the end user at high speed rates, the battery and energy requirements of IoT devices must be met or exceeded with support for battery-free IoT devices and efficiency of AI support. The strength of AI in this regard will require another important element of the 6G architecture: massive low-latency and ubiquitous connectivity.

Just as it has done for its 5G satellite partners, ESA will provide the framework for its industrial partners to succeed in the 6G economy. Research and development for state-of-the-art satellite technology aimed at the 6G market is costly, and therefore requires additional infrastructure to support implementation. Part of this rollout will be the successful implementation of governmental advisory board requirements, coordination of work plans for 6G and a unified strategy for seamless integration of terrestrial and satellite infrastructure.

3.8. STANDARDISATION

To demonstrate its commitment to the adoption of 5G and 6G in telecommunications, ESA participates in the 3rd Generation Partnership Project (3GPP), a telecommunications standards development organisation. ESA takes part in 3GPP standardisation meetings and continues to offer strong support to standardisation work performed by an industrial consortium for satellite integration in 5G and 6G. The principal objective being to ensure that future communication network standards properly account for the integration of satellite systems and hence create opportunities for the broader satellite telecommunications industry. As part of this activity, a Satellite Special Interest Group (SSIG) convenes and coordinates the views of all interested space stakeholders. As 6G standards evolve over the next decade, with implementation rolled out in the 2030 timeframe, it is imperative to progress research on enabling technologies and demonstrations now, to inform and drive the standardisation to include satellites from the outset in the 6G era.

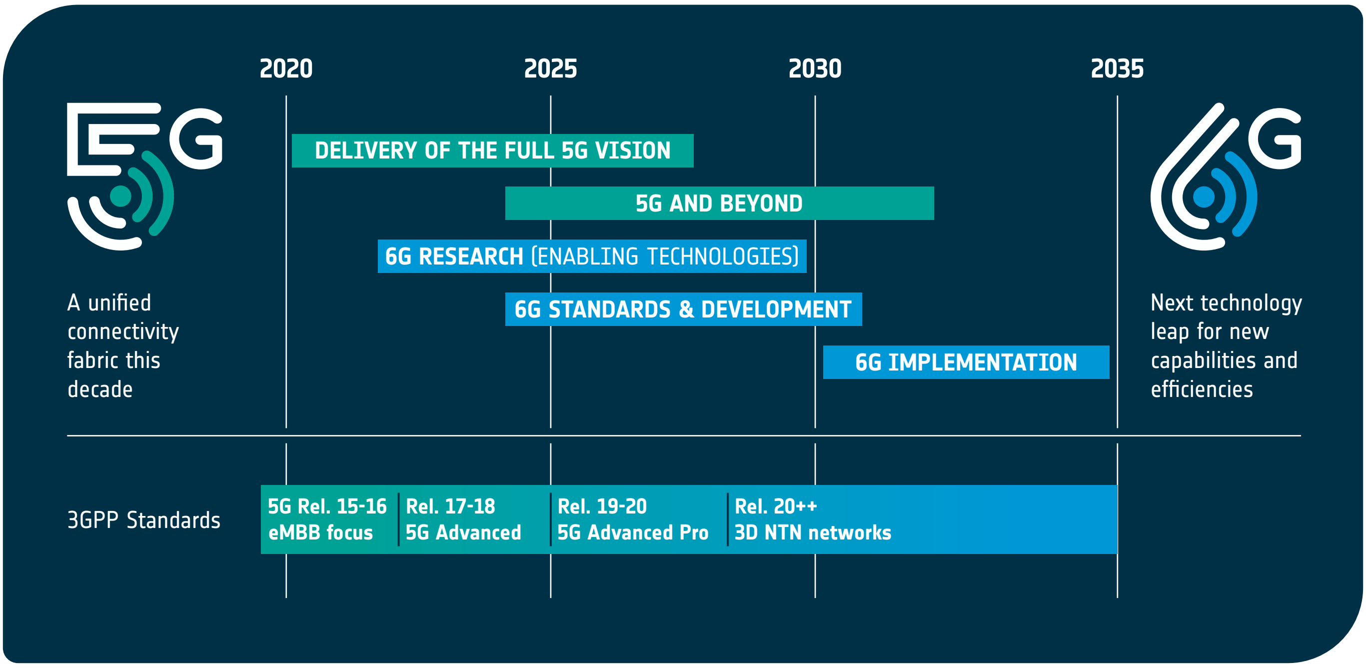


Figure 6: 5G and 6G Standardisation Roadmap

3.9. ROADMAP TO 6G

The path to 6G implementation within ESA will be guided by the 5G/6G Strategic Programme Line (SPL) Roadmap comprised of, but not limited to, the following elements:

Governance and Outreach

The 5G/6G SPL Roadmap is formulated and continuously reviewed and updated in coordination with the 5G Advisory Committee and endorsed by the JCB and its 5G Advisory Committee. Coordination and harmonisation with the European Commission's 5G and 6G initiatives is of strategic importance for the success of 5G and 6G alike, and will remain a staple within ESA's 5G/6G SPL.

5G/6G Strategy

The requirement for seamless integration of space and terrestrial telecommunications assets is a driving force behind the 5G/6G SPL Roadmap. Implementing space networks and satellite constellations will fulfil present and future connectivity demands that European industry partners and end users require. Sustainability always remains at the forefront and a key element in our strategic formula.

5G/6G Standardisation

The 5G/6G SPL strongly supports space stakeholders and will continue to guide organisations in the direction of 5G and 6G standardisation. It is of paramount importance that space networks are part of the 5G and 6G family of standards in order to achieve seamless global connectivity, and to realise all the technological opportunities outlined in this white paper.

5G/6G Work plans

Part of the technology roadmap is composed of a set of essential technology developments for 5G and 6G, tendered by ESA to the space industry in Europe and Canada. These activities are typically fully funded, each focusing on a specific area of 5G and 6G requiring low technology-readiness-level developments. The nine categories are:

5G.01 - Standardisation/Licensing/Regulatory Support

As outlined above, standardisation is a strategic step that will be supported to ensure future compatibility and interoperability of technologies within the terrestrial cellular standards. The 3GPP's recognition of the 5G New Radio (NR) Non-Terrestrial Network (NTN) inculcates the great efforts made to towards standardisation. Additional support towards the standardisation of satellite 5G and 6G components is indeed foreseen, and will be implemented as part of ARTES 4.0 Future Preparation activities.

5G.02 - 5G/6G System Infrastructure Studies

All technologies and system architectural options that might form the basis for European and global next generation 5G/6G infrastructure will be identified. Through our analyses we will determine technology readiness levels and identify gaps our industrial partners must address before 6G arrives on the scene. The studies focus on three key areas: the overall system, the space segment, and the ground segment. The orbital testbed/6G laboratory will play a critical role in this infrastructure assessment.

5G.03 - 5G/6G New Radio – Radio Access Network Developments

The development of radio access network techniques and protocols compliant with the recently released 5G standard will be crucial towards 6G network development. This protocol will be fully supported in order to enable direct access via satellite to terrestrial communication networks, and therefore provide full integration and compatibility for 6G.

5G.04 - 5G Core Network Developments

The interoperability of satellite networks with terrestrial 5G core networks is of paramount importance to guarantee full network convergence when 6G takes over. A set of development activities are being explored under this category to address any interoperability issues before they arise.

5G.05 - 5G/6G Testbed Infrastructure

Adequate infrastructure is required to test the future 5G/6G network functions, protocols and security for 5G and 6G satellite nodes—enter the 6G laboratory in space. Additional efforts will be initiated to find solutions to potential security vulnerabilities introduced by the adoption of 5G and 6G space features.

5G.06 - 5G/6G Universal Satellite-Terrestrial User Equipment

This category aims at supporting industry in developing universal efficient and cost-effective user terminals (both satellite and terrestrial). To achieve the required economies of scale, it is important that essential user equipment building blocks compliant with these standards will be shared with industry so that they can be competitive toward 6G technologies.

Activities within this category will focus on developing engineering breadboards, reference protocol stacks and any required modifications to existing equipment to enable 5G and 6G satellite connectivity and integration.

5G.07 - 5G/6G Hub for Over-The-Air Validations

There is a degree of scepticism regarding the integration of satellite with terrestrial networks, based on historical challenges with mobile network operators. These misconceptions will be easily overcome through promotion, education and validation of the 5G and 6G technologies on the horizon. The 5G SPL introduces a development-to-validation approach aimed at validating over-the-air the developments undertaken through the categories previously described in realistic conditions, namely, using existing space infrastructure. Through this practical and real-world application, the adoption of 5G and 6G satellite technologies will be encouraged, yet another excellent example of how the 6G laboratory and space-based testbed will benefit European Industry.

5G.08 - 5G/6G Satellite Proof-Of-Concept Missions

A set of 5G/6G satellite proof-of-concept missions will be proposed to develop state-of-the-art activities that will prove the need for new space infrastructure in order to demonstrate the capabilities of 5G and 6G that industry demands (always complementary to existing 5G Hub over-the-air validation blocks). For example:

- Demonstrate the functionalities of a 5G gNodeB in space as well as a direct 5G broadband access from low Earth orbit to very small aperture mobile terminals (proposed in the 5G SPL Work Plan 2021)

- Realise a 6G Satellite precursor as proposed in Work Plan 2023. The objective is to develop an in-orbit 6G Laboratory, where technologies and techniques key to the role of satellites in 6G networks will be tested and validated. This includes novel techniques such as AI-assisted dynamic spectrum allocation, AI-assisted dynamic service-based resource management, self-optimised air interface, characterisation of sub-THz transmission performance, neuromorphic processors, sub-millimetre-wavelength radio frequency equipment and antennae, cognitive radios, software-defined radios and software-defined payloads. These are just a few of the elements that, from space, can help to inform what 6G needs and demands on terrestrial networks might look like.

5G.09 - Beyond 5G (B5G) and 6G
Before 6G takes the stage, the interim period between 5G and 6G is known as 5G and Beyond (B5G). The 5G and Beyond Roadmap is rapidly evolving alongside the 3GPP standardisation process, with B5G to be specified in the next releases (rel.18 to 20) and 6G after that (rel. 21 upwards). With the establishment of satellites as part of release 17 and beyond, it is important to begin identifying essential building blocks to support and align to subsequent 3GPP releases B5G and 6G. For this reason, a new category has been added to the 5G/6G Work Plan classification in order to prepare the next stages of development towards 6G..

5G/6G Product and Technology
This element of the roadmap covers the development of products and services across the space, ground and user segments. These industry-initiated activities are assessed on a case-by-case basis in coordination with the support of ESA Member States Delegations.

5G/6G Flagships and Partnerships
Partnerships between industry and ESA are formed to focus on specific market opportunities in 5G and 6G, with the participation of satellite network operators, terrestrial cellular operators, technology developers, and vertical market stakeholders of one or more 5G/6G vertical markets or use cases.

5G/6G Applications
The 5G/6G SPL also supports the development and trials of any applications or services enabled by seamless 5G/6G connectivity, across all vertical markets and use cases. Just get in touch!

5G/6G Hub
In the spirit of the promotion of validation activities, a state-of-the-art 5G/6G Hub has been built at ESA's European Centre for Space Applications and Telecommunications (ECSAT) at Harwell in the UK. The 5G/6G Hub enables stakeholders from different industries to collaborate, develop and test new 5G solutions. The Hub acts as a catalyst for the proliferation communities working on 5G/6G activities across ESA Member States to facilitate their engagement and collaboration with one another.

The success of the 5G/6G Hub in ECSAT has led to its expansion in 2023 to include a new Digital Health room focused on the “One Health” goals for human and planetary health, with plans for new exciting hubs across ESA sites in Europe to foster collaborative and innovative 5G / 6G solutions.

Figure 7: The 5G/6G Hub

5G/6G Communications and Outreach

It is important that ESA and its partners continue to promote the use of space in the 5G/6G ecosystem, by strengthening its online and social media presence. As end users start to see 5G appear in the upper corners of their cellphones, some will undoubtably ask, “what comes next?” Thankfully, many industry partners and ESA encourage a social media presence that educates and interacts with a wide gamut of users.

Through outreach events, the prospects of 6G can be demonstrated through interactive exhibits, websites, VR apps, industry open days and more. Once more IoT and IoMT devices become available utilising the features of 5G and 6G, the standard will prove itself on merit alone.

Figure 8 provides a high-level view of ESA’s Space for 5G and 6G roadmap.

6G ROADMAP ELEMENTS	5G 2023	6G 2026+
Governance/Outreach	**Governance** JCB - 5JAC	**Outreach** Satcom Ecosystem 5G Terrestrial Ecosystem European Commission
5G/6G Strategy	**Seamless Integration**	**SDGs**
5G/6G Standardisation	**5G Advanced** Rel. 17-18	**6G** Rel. 19-20
5G/6G Work Plans	**Flying gNB**	**6G-In-orbit lab** **D-band**
5G/6G Product & Technology	**5G Payloads** **5G Networks** **AI/ML**	**6G Space Networks**
5G/6G Flagships 5G/6G Applications	**Sustainable Mobility** **Autonomous Ships** **Agriculture** **Autonomous Cars** **5G Broadcast**	**6G Satellites** **6G Systems** **Sustainable Mobility** **Digital Health** **Sustainable Planet**
5G/6G Hub	**First 5G Install** **Satellite Uplinks** (GEO/LEO)	**AR/VR/XR** **AI/ML** **Metaverse**
Comm. Outreach	**5G Web Page** **5G Brochure** **5G Video**	**6G Web Page** **6G e-presence**

Figure 8: 6G Roadmap Elements

4. SUMMARY

Connectivity in the next decade will be universal and ubiquitous thanks to the convergence of terrestrial and non-terrestrial networks. The new 6G standards will encompass multi-layered network topologies, with intelligent orchestration of terrestrial, geostationary and non-geostationary satellite networks, for the provision of global, seamless and ubiquitous communications. The next generation of wireless standards will fulfil the promises of their predecessors. 6G will deliver.

As bandwidth demands are driven up, higher frequency ranges—from W-band to D-band—will be available and accessible to meet people's needs.

New services and applications are being developed to take advantage of 6G standards, covering all aspects of society and industry. Applications will focus on sustainable connected autonomous systems, broadcasting, planetary health, digital healthcare, smart cities and smart infrastructure – and much more.

Increased network automation, dynamic self-reconfigurability of satellite and terrestrial equipment, cybersecurity and network sensing will be key drivers behind an intelligent connectivity fabric fueling the 6G economy of tomorrow.

Space-based 6G network nodes with onboard intelligence, edge computing and network functions will blend seamlessly into that of terrestrial networks to provide instant global connectivity—and resilient coverage for all areas of the planet.

ESA stands ready to support European and Canadian space industries with a technology roadmap to promote competitiveness, sovereignty, and autonomy. ESA will continue to prepare space to support and energise the lucrative 6G economic landscape ahead. In the future, when we visit those villages of the Cotswolds, our hands won't be holding up a mobile phone in search of connectivity. We will hold our hands up instead to greet our loved ones – and welcome them, confident that no connection will be lost.

Get in contact:
Scan this QR code to email us

5. REFERENCES

5GAA Position on the Secure Space-Based Connectivity Programme and Focus on the European Communication Satellite Constellation – 5G Automotive Association. (n.d.).
https://5gaa.org/news/5gaa-position-on-the-secure-space-based-connectivity-programme-and-focus-on-the-european-communication-satellite-constellation/.

6G Flagship. (2020, September 11). Challenges for 6G Addressing a Sustainable Future – What Is Missing Today? [Video]. YouTube. https://www.youtube.com/watch?v=5UbhepOQGK8

ASCENT. (2020). Ascent strategic recommendations: Spectrum sharing between satellite and terrestrial systems. [White Paper].

Dahmen-Lhuissier, S. (n.d.). ETSI - Reconfigurable Intelligent Surfaces. ETSI.
https://www.etsi.org/technologies/reconfigurable-intelligent-surfaces.

Downey, A. (2019, August 19). Knowledge of 5G potential needs to be embedded into NHSX, report finds. Digitalhealth.Net.
https://www.digitalhealth.net/2019/08/knowledge-5g-potential-embedded-nhsx/.

Downstream Gateway: bringing space down to Earth. (n.d.).
https://www.esa.int/About_Us/Corporate_news/Downstream_Gateway_bringing_space_down_to_Earth.

Energy Self-Sustainability in Full-Spectrum 6G. (2021, February 1). IEEE Journals & Magazine | IEEE Xplore.
https://ieeexplore.ieee.org/abstract/document/9261955.

European Space Agency, Telecommunications and Integrated Applications. (2021) From 5G to 6G: Space Connecting Planet Earth For A Sustainable Future. [White Paper].

European Space Agency, Telecommunications and Integrated Applications. (2022). The Car of The Future Connected From Space. [White Paper].

Hassani H, Huang X, MacFeely S. Impactful Digital Twin in the Healthcare Revolution. Big Data and Cognitive Computing. 2022; 6(3):83.
https://doi.org/10.3390/bdcc6030083.

J. Hu, Q. Wang and K. Yang, "Energy Self-Sustainability in Full-Spectrum 6G," in IEEE Wireless Communications, vol 28, no. 1, pp. 104-111, February 2021,
https://doi.org/10.1109/MWC.001.2000156.

K. B. Letaief, W. Chen, Y. Shi, J. Zhang and Y. -J. A. Zhang, "The Roadmap to 6G: AI Empowered Wireless Networks," in IEEE Communications Magazine, vol. 57, no. 8, pp. 84-90, August 2019. https://ieeexplore.ieee.org/document/8808168.

Knack, A. (2018, February 19). How VR and AR could transform the health sector. Digitalhealth.Net. https://www.digitalhealth.net/2018/02/vr-ar-transform-health-sector/.

Matinmikko-Blue, M. (2021, October 25). 6G and the UN SDGs: Where is the Connection? SpringerLink. https://link.springer.com/article/10.1007/s11277-021-09058-y?error=cookies_not_supported&code=f2ec625e-5114-482b-b332-3989ba268145.

Next G Alliance / Alliance for Telecommunications Industry Solutions. (2022). Next G Alliance Report: 6G Applications and Use Cases [White Paper].

Next G Alliance / Alliance for Telecommunications Industry Solutions. (2022). Next G Alliance Report: Roadmap to 6G [White Paper].

Next G Alliance / Alliance for Telecommunications Industry Solutions. (2022). Next G Alliance Report: 6G Technologies [White Paper].

Nokia. (n.d.). How Artificial Intelligence reduces the carbon footprint of telco networks. https://nokia.com.

One 6G. (2022). 6G Vertical Use Cases: Descriptions and Analysis [White Paper].

Space for 5G. (n.d.). ESA TIA. https://artes.esa.int/space-5g.

Sunrise. (n.d.). ESA TIA. https://artes.esa.int/projects/sunrise.

The 5G Infrastructure Association. (2021). European Vision for the 6G Network Ecosystem [White Paper].

Unity Technologies. (2022). The What, Why And How Of Digital Twins. Unity.com.

W. Tong and P. Zhu (Eds), 6G: The Next Horizon: From Connected People and Things to Connected Intelligence, Cambridge University Press, 2021.

Williams, A. (2021, June 1). OneWeb's Joey-Sat to demo beam-hopping satellites. Electronics Weekly. https://www.electronicsweekly.com/news/onewebs-joey-sat-demo-beam-hopping-satellites-2021-05/.