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Working Party on Communication Infrastructures and Services Policy

Draft Spotlight: Next generation networks and the connectivity ecosystem

OECD Digital Economy Outlook 2024, Volume 1

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The present document presents a draft Spotlight article for the OECD Digital Economy Outlook 2024, Volume 1, on "Next generation networks and the connectivity ecosystem", based on a draft outline that was presented at the 90th CDEP session on 16 December 2022 [DSTI/CDEP/CISP(2022)3].

This spotlight is a contribution from the Working Party on Communication Infrastructures and Services Policy (WPCISP). It was written by the OECD CISP Secretariat and the Chair of the WPCISP, Bengt Mölleryd.

Action: WPCISP delegates are invited to provide written comments by 5 May 2023.

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NOTE BY THE SECRETARIAT

OECD Digital Economy Outlook 2024: Spotlight on "Next generation networks and the connectivity ecosystem"

1. The CDEP and its Working Parties considered orientations for the 2024 edition of the OECD Digital Economy Outlook (DEO) at their meetings in Spring 2022 [DSTI/CDEP(2022)2] and a draft annotated outline and timeline at the 27-28 September 2022 CDEP meeting [DSTI/CDEP(2022)8]. A revised annotated outline and timeline was published on ONE on 26 October [DSTI/CDEP(2022)8/REV1].

2. The DEO is envisaged to include the following:

- **Volume 1: Economic and technology outlook** (including this "spotlight" prepared by the WPCISP)
- **Volume 2:**
  - **Part I.** Digital performance and policy trends
  - **Part II.** Towards a more connected, trusted, and green digital future (including Chapter 7 on Access and Connectivity led by WPCISP)
- **Statistical annex** (including WPCISP data)

3. A "spotlight" in the DEO is a self-contained piece written in an accessible style, with a maximum length of 10 pages including endnotes. This document proposes the draft spotlight on "Next generation networks and the connectivity ecosystem". It explores how next generation wireless networks may evolve in the short- to medium-term (e.g. the next five to ten years). While the spotlight may touch upon how policy may need to progress, the thrust of the article is on the technology itself and how it may impact the connectivity ecosystem.

4. The WPCISP will also lead the drafting of Chapter 7 (in Volume 2) on Access and Connectivity and, as relevant, and is supporting the preparation of other DEO chapters, in areas such as the environmental sustainability of communication networks.

5. This spotlight on "Next generation networks and the connectivity ecosystem" will be included in Volume 1 of the DEO 2024. An indicative timeline for producing the spotlight can be found below (Table 1).

Table 1. Indicative timeline for this spotlight

Timeline	
Outline of the spotlight published on ONE for feedback and written comments from WPCISP and CDEP by 16 January 2023, following the 89th CDEP meeting in December	23 November 2022
First draft of Spotlight article presented at the 66th meeting of the WPCISP for feedback and comment	**13-14 April 2023**
Final draft of the spotlight to CDEP for approval and declassification, pending exact meeting dates.	Q4 2023
Launch of DEO Volume I (including the spotlight on *Next generation networks and the connectivity ecosystem*)	Q1 2024

Action required: WPCISP delegates are invited to provide written comments by **5 May 2023**.

Spotlight: Next generation networks and the connectivity ecosystem

Future demand is triggering changes in the connectivity ecosystem and next generation networks

6. Next generation communication networks are driven by technological developments in the communications industry as well as current and future demand on networks. The amount of data sent over communication networks has increased steadily, spurred by developments in Artificial Intelligence (AI) systems and the Internet of Things (IoT), and the combination of both technologies. While predicting future demand on networks is not without challenges, enhanced machine and human communications and interactions are likely to play important roles as well as human-augmenting technologies for sensorial communication, including haptics (Internet-of-senses). In addition, fully automated vehicles, for example, will shape future demand on wireless networks.

7. The combination of virtual reality (VR), augmented reality (AR), and extended reality (XR) environments and applications are not only shaping human communications, but also the way humans communicate with machines and their environments as the digital, human, and physical world merge (Hexa-X, 2022[1]). This topic will be explored in Chapter 3 of the Digital Economy Outlook (DSTI/CDEP(2022)23) and will require existing broadband networks to adapt in the future. Moreover, haptic technologies – which are still relatively nascent – are advancing together with AR applications and are starting to be used in areas such as surgery simulations, immersive communication, health care and for visually and hearing-impaired people.

8. All these advances have important implications for future networks: they generate large amounts of data, leading to higher bandwidth and data processing requirements. Most of these applications also rely on improved broadband performance, i.e. higher speeds and lower network response times (latency). On top of these network performance requirements, increased network resilience will be needed, not only for critical applications, but for all use cases. Most importantly, broadband networks have evolved from connecting people, to connecting "everything", towards the next step of providing unlimited and embedded connectivity "everywhere" in the future. As such, a key question is how networks, and in particular wireless networks, need to be shaped in the future to respond to these technological developments.

9. A better understanding of the connectivity ecosystem is essential to ensure evidence-based policy making. Bearing in mind that the OECD sets policy and not technological standards and considering that technological futures have a high degree of uncertainty in a dynamic area such as communication infrastructure and services, this Spotlight intends to shed light on possible developments in next generation wireless networks in the upcoming five to ten years, highlighting the potential to extend high-quality connectivity 'everywhere' and complementing OECD work on trends driving the networks of the future, such as a higher level of integration of cloud into networks, edge computing, virtualisation, and network automation (OECD, 2022[2]). While this Spotlight focuses on wireless networks, extending fibre deeper into networks is critical for all access technologies to increase network performance and reliability.

10. Two important developments are likely to shape wireless communications in the next decade. First, "beyond 5G" terrestrial technologies, which are expected to push performance boundaries in wireless communications. Second, non-terrestrial networks, including low earth orbit (LEO) satellite constellations and different types of aerial platforms. An important question arises around the potential integration of terrestrial networks (TN) and non-terrestrial networks (NTN), that while being wireless, are technically very different. Research initiatives have emerged that assess the question of how to integrate these network types (i.e. hybrid connectivity topologies). In the future, hybrid satellite and terrestrial wireless networks could, for example, provide connectivity solutions for customers using IoT, maritime, and aviation applications (OECD, 2022[2]).

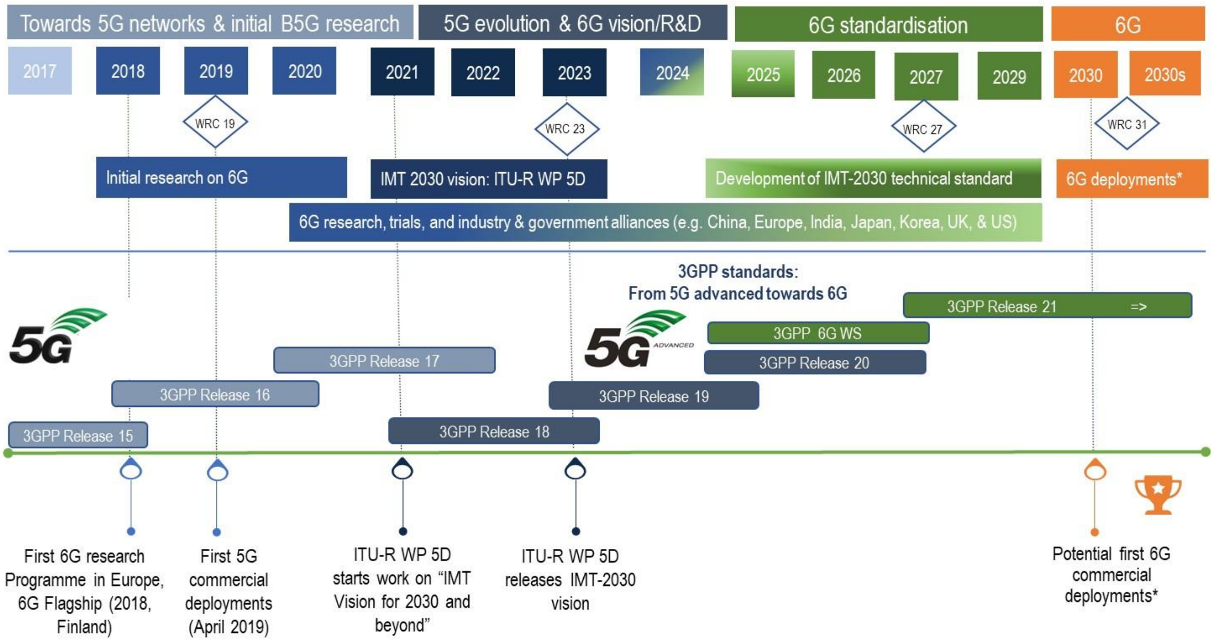
Section 1. Terrestrial connectivity: Beyond 5G technologies

11. What are "beyond 5G", or sometimes referred to as "6G", technologies? This is yet to be defined. Several countries, research institutes and the network industry are embarking on research activities beyond 5G mobile technologies with an expected commercial launch at the end of this decade (OECD, 2022[2]). The ITU-R Working Party 5D, for example, started its work on the "Vision of IMT beyond 2030" in 2021 (ITU, 2021[3]) and has set a timeline aiming for the International Mobile Telecommunications (IMT) 2030 specifications to be completed by the end of 2029 (ITU-R, 2022[4]).[1]

12. Figure 1 shows an illustrative timeline of 6G development. While 6G research is ongoing in several countries (e.g. in the People's Republic of China, the European Union, Finland, Germany, Japan, Korea, Singapore, the United Kingdom and the United States), the vision for the next evolution of mobile networks is being conceived in the context of current 5G network deployments. As of February 2023, 5G commercial deployments were available in 36 out of 38 OECD countries. While most 5G commercial networks to date have been based on non-standalone (NSA)-5G (i.e. relying on a 4G core network and using NSA-5G standards in the radio interface), standalone (SA)-5G deployments are on the rise. Many of the promised transformational aspects of 5G are likely to commence with SA-5G networks that use both the 3rd Generation Partnership Project (3GPP)[2] core network architecture standards for 5G (i.e. 5G Core, 5GC), as well as the 5G radio interface (i.e. New Radio, NR) (OECD, 2022[2]). As such, the 5G standard will continue to evolve, with 3GPP already announcing "5G advanced" for the upcoming releases (3GPP Releases 18 to 20 for "5G Advanced") that will lead to 6G.

13. The vision of IMT beyond 2030 that the ITU-R Working Party 5D plans to publish by the end of 2023, will set the main specifications for beyond 5G technologies. This will allow standard setting bodies to work on mapping these identified key values and specifications into technical standards. The actual standardisation process of 6G will likely commence after 2025, with the first commercial deployments perhaps occurring around 2030. Preparatory work to identify new spectrum for 6G ("IMT for 2030 and beyond") is ongoing and will be discussed during the ITU World Radiocommunication Conference (WRC) 2023 with a view to incorporate it as an Agenda Item for WRC 2027 (Figure 1).

Figure 1. The road to 6G: Potential timeline*



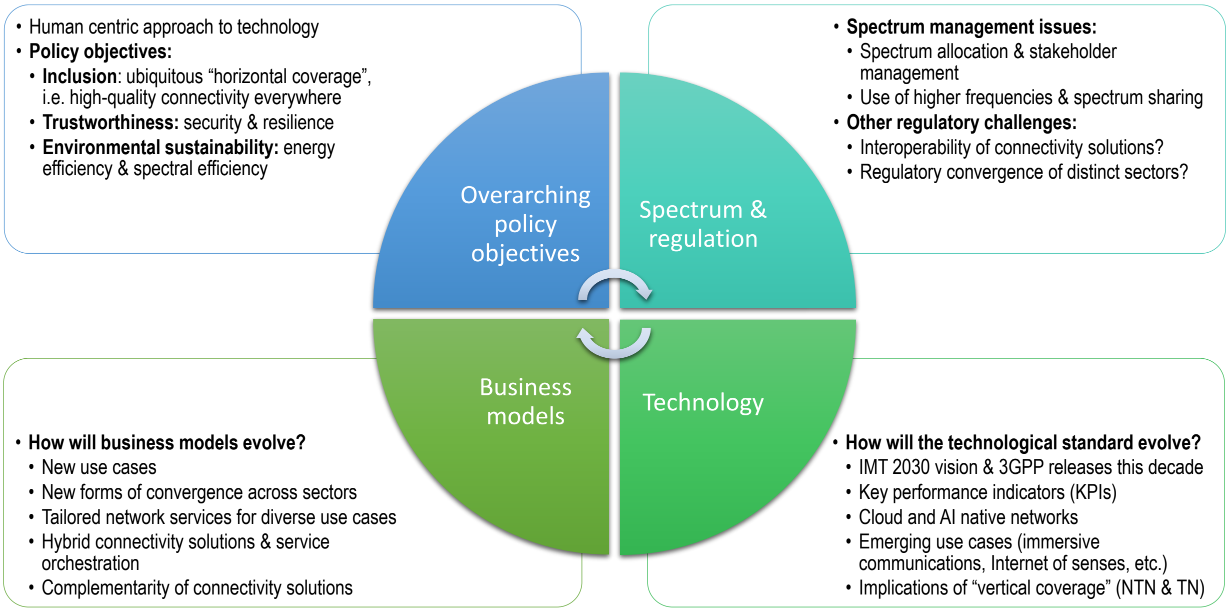
Note: B5G= Beyond 5G. *Descriptive and tentative timeline for illustrative purposes. Development and commercial launch of 6G depends on multiple factors, including, but not limited to, when different countries start to deploy.

Source: Own elaboration based on desk research from several sources. These sources include: presentations from different stakeholders at the June 2022 ITU-R Workshop on "IMT for 2030 and Beyond" (ITU-R, 2022[5]) [e.g. Wireless World Research Forum, Samsung Research, HAPS Alliance, European 6G Flagship Hexa X, NextG Alliance (United States); Beyond 5G Promotion Consortium (Japan), one6G Association (Greece); "6G: Building Metaverse ready Mobile Networks" and "Use cases" (several universities), Finish Transport and Communications Agency; Telecommunications Standards Development Society in India]; (Ahokangas, Matinmikko-Blue and Yrjölä, 2023[6]), "Envisioning a Future-Proof Global 6G from Business, Regulation, and Technology Perspectives", IEEE Communications Magazine; Qualcomm (2022[7]), "Vision, market drivers, and research directions on the path to 6G", https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/Qualcomm-Whitepaper-Vision-market-drivers-and-research-directions-on-the-path-to-6G.pdf; Ericsson (2022[8]), "6G: Connecting a cyber-physical world", https://www.ericsson.com/4927de/assets/local/reports-papers/white-papers/6g--connecting-a-cyber-physical-world.pdf; and 3GPP (2023[9]), "Releases", https://www.3gpp.org/specifications-technologies/releases.

14. While these 6G discussions are nascent, they will combine evolutionary aspects, building on 5G wireless networks, as well as more revolutionary aspects, such as terahertz communication and sensing, combined with new frequency bands being used (OECD, 2022[2]). For example, researchers assume that the integration of sensing information and time synchronisation may enable new applications for interactive and multiparty connectivity, within and between virtual and physical worlds (ITU-R, 2022[10]).

15. Like previous generations of mobile networks, several interrelated factors will likely shape what the future of mobile wireless networks may look like and their impact on the evolving connectivity ecosystem. These factors include: 1) the overarching policy objectives or key values being considered for the next generation of mobile networks; 2) spectrum management issues and other regulatory challenges; 3) the evolution of the technological standard itself based on research, trials and emerging use cases; and 4) the implementation of use cases through evolving business models (Figure 2).

Figure 2. Interrelated factors that will likely shape 6G during the next decade



Note: NTN=Non-terrestrial networks; TN= terrestrial networks. Definitions: *Resilience* of communication networks refers to the ability of a network to cope with shocks, while still maintaining an acceptable level of service. It can be strengthened by ensuring network diversity and redundancy when planning and rolling out infrastructure. A *digital security incident* is an intentional or unintentional event that can disrupt the availability, integrity and confidentiality of data, information systems and communication networks.
Source: Own elaboration based on desk research on the different 6G visions being discussed (as of February 2023). Sources include: presentations from different stakeholders at the ITU-R Workshop on "IMT for 2030 and Beyond" (ITU-R, 2022[5]); (Ahokangas, Matinmikko-Blue and Yrjölä, 2023[6]), "Envisioning a Future-Proof Global 6G from Business, Regulation, and Technology Perspectives", IEEE Communications Magazine, Working Paper; and (Policy Tracker, 2023[11]), "Do 5G and 6G change spectrum policy?, https://www.policytracker.com/blog/our-new-podcast-spectrum-policy-101/.

16. ***Spectrum management and regulatory issues.*** Some of the use cases being researched for 6G include the use of higher spectrum bands, such as millimetre wave (above 24 GHz) and Terahertz spectrum (above 100 GHz). For example, in December 2022, ETSI launched an industry specification group on Terahertz communications as a potential candidate for 6G focusing on data intensive applications such as VR and AR, and applications merging sensing and communication functionalities, such as holographic telepresence (ETSI, 2022[12]). It is very likely that low and mid-band spectrum will continue to play a key role (GSMA, 2023[13]), and as such, spectrum sharing models will only increase in importance. Moreover, as new players from distinct sectors become more prominent in the wireless broadband connectivity ecosystem, spectrum allocation and stakeholder management will become even more critical. Other regulatory challenges, apart from spectrum policy, include how to ensure the interoperability of diverse connectivity solutions, and how to deal with the convergence of distinct sectors that may not be under the remit of communication regulators.

17. ***Technology development and use cases.*** Looking at potential use cases, some researchers believe that 6G may catalyse new use cases providing ubiquitous communication as well as high accuracy and low-latency joint communication, sensing and positioning systems (Ofcom, 2021[14]; Bourdoux et al., 2020[15]).[3] Ubiquitous coverage and enhanced quality of experience may be enabled both by ongoing research on the use of smart surfaces made of artificial materials ("metamaterials") deployed along streets and buildings to go beyond the traditional physical wireless limits, as well as moving towards hybrid terrestrial-aerial topologies (Ofcom, 2021[16]). Examples of applications being discussed for 6G technologies include advanced multimedia services such as immersive XR, holograms, digital twins, three-dimensional (3D) calls, haptic communication (i.e. the transmission of touch and motion), fully automated

mobility solutions, and nano-technology-inspired IoT sensors (FierceWireless, 2021[17]). Researchers point to the need for 6G to be cloud and AI native from the start to optimize network management, energy consumption, spectral efficiency and to provide enhanced digital security features. In addition, fully virtualised and software defined networks may support cost effective and backward compatible solutions to achieve inclusion objectives given that countries are likely to deploy 6G networks at different stages (Wireless World Research Forum, 2022[18]). There are also emerging applications in the automotive sector (fully automotive vehicles), healthcare (e.g. AI-tailored wireless hospitals) and industry (VR, AI, edge computing and robotics) (6G Flagship, 2023[19]). Moreover, ongoing research on 6G has also focused on expanding "vertical coverage" with the integration of cellular terrestrial networks (TN) with non-terrestrial networks (NTN), which could include High Altitude Platform Stations (HAPS), satellites in low-Earth orbit (LEO), medium Earth orbit (MEO), geostationary orbit (GEO), air-to-ground (A2G) networks and other aerial platforms (see Section 3).

18. ***Business models***. Given that standalone 5G is yet to become a reality in most countries, some stakeholders are considering first how 5G will impact the digital transformation prior to 6G networks becoming widely accessible. In particular, the implementation of 5G-SA use cases may shed light on future applications and business models for 6G where connectivity may become "network-as-a-service" for tailored use cases. Some of the challenges with SA-5G deployments, where the promise of the revolutionary aspects of 5G would spread across all sectors of the economy, may help when thinking of the future, including what type of partnerships will be required to reap the societal benefits of 6G. With this backdrop, it is likely that new forms of collaboration will develop across different sectors with the advent of hybrid connectivity solutions and multi-layered networks. Questions on whether different connectivity solutions are complements or substitutes will likely shape business models. Moreover, models to monetise projected use cases, which is a contemporaneous concern for 5G, will likely also be a main discussion driving future business models in the next generation of wireless networks.

19. There is an array of open questions as 6G is being developed. Will we have a hyper-connected world in 2030? If so, what are the implications? Importantly, what are the network requirements? Are there new risks and challenges? In terms of connectivity requirements, how do we ensure efficient spectrum management for a variety of use cases requiring stakeholder management? How to foster investment, and how to work together to build an ecosystem where IoT and AI applications are agnostic to borders? In such a future, common approaches to regulation and policy across countries are needed as well as interoperable standards.

Section 2. Non-terrestrial connectivity: Developments in satellites and other aerial wireless technologies

20. Satellites in Non-Geostationary Satellite Orbit (NGSO) have started to provide broadband connectivity to end users, especially in under- or unserved areas by terrestrial networks (e.g. rural and remote areas), and to support terrestrial networks by offering backhaul services. In addition, other aerial technologies are under development to bridge connectivity divides, and first efforts are taking place to integrate terrestrial and non-terrestrial networks.

Non-geostationary orbit (NGSO) satellite constellations

21. The advances in satellite technology, coupled with improvements in launch capabilities and a reduction in the cost and size of terminal devices, have lowered barriers to entry and expanded the array of satellite-based connectivity solutions. The emergence of different constellations, aiming to provide end-user communication services (e.g. Starlink, OneWeb, Kuiper), especially in rural and remote areas, is complementing the connectivity ecosystem. Moreover, there is an increasing number of satellites targeted to provide IoT solutions in remote areas or aimed for the logistics sector, including for aircraft and maritime

coverage (e.g. Swarm Technologies, Hiber, Kinéis and Globalstar). All these applications strive at achieving connectivity "everywhere".

22. Satellite connectivity in the past has largely been provided using satellites in geostationary earth orbit (GEO), which are synchronised with the Earth's rotation. While GEO satellites have a large coverage area, they are typically more expensive to build, and suffer from higher latency as radio signals have to travel back and forth to the geostationary orbit in 36 000 km altitude. Newer approaches propose satellites in low earth (LEO) or medium earth orbit (MEO), also known as non-geostationary orbit (NGSO) satellites, which are cheaper to build and launch, depending on the size and complexity of the satellite (OECD, 2017[20]). However, their lower orbits require many more satellites to complete a worldwide constellation.

23. Several companies have plans to or have already launched LEO constellations to offer satellite connectivity, including Starlink, OneWeb, Boeing, Telesat and Amazon's Project Kuiper. While Starlink and OneWeb are deploying their constellations now, Project Kuiper plans to launch its first commercial services in mid-2025. As of February 2023, Starlink had 3 154 active satellites in orbit and OneWeb 544 satellites, with 441 operational (Planet 4589, 2023[21]). In December 2022, SpaceX's Starlink launched 54 second generation satellites to new orbits to add capacity to its network using the 27- 30 GHz bands. SpaceX noted that those will allow them to "add more customers and provide faster service, particularly in areas that are currently oversubscribed" (Space.com, 2022[22]).

24. The new generation of satellites, referred to as high-throughput satellites (HTS), use the 4-8 GHz, 12-18 GHz, and 27-40 GHz-bands, with wide beams, spot beams, and frequency-reuse technology. This could enable satellites to increase performance and capacity per satellite.[4] Consequently, smaller remote terminals can be used, lowering equipment cost, with increased power and bandwidth providing faster speeds (OECD, 2022[23]). In addition, inter-satellite links are also advancing to allow for quicker transmission between satellites (IETF, 2022[24]).

25. At present, new advances point to the possibility of using connectivity from satellites for mobile terminals through messaging services facilitated by the inclusion of satellites in the 3GPP standard Release 15 and onwards.[5] Some mobile communication operators are striking partnerships with satellite providers to expand the coverage of their network, for example, T-Mobile in the United States partnered with Starlink to provide text service to its clients in all areas of the United States, including national parks and other remote regions (T-Mobile, 2022[25]). There is also increasing momentum from the device ecosystem. Several smartphone equipment manufacturers (e.g. Apple, Samsung), chipset providers (MediaTek, Qualcomm), and mobile operators have announced developments to link mobile phones to satellites for emergency communications (Apple, 2023[26]; CNBC, 2023[27]; Forbes, 2023[28]; Qualcomm, 2023[29]).

26. In the United States, the FCC notes that given the increase in applications for new satellites, featuring new commercial models, players, and technologies, it has created a "space bureau" to support the burgeoning satellite industry. The FCC has also adopted rules to shorten the deorbiting period for low-earth orbit satellites from 25 to 5 years, and issued in December 2022 a Notice of Proposed Rulemaking to streamline its review processes for satellite applications (FCC, 2022[30]).

27. The European Commission recently announced plans for an "EU space-based secure connectivity system" leveraging satellite connectivity (European Commission, 2022[31]). In November 2022, the EU Parliament and EU Council announced a provisional agreement for a satellite constellation, Iris, that will include GEO, MEO and LEO satellites (European Parliament, 2023[32]). This will support EU priorities in terms of connectivity, both for government users as well as residential and enterprise users, to support the economy, environment, security and defence (European Commission, 2022[33]).

28. Other governments are considering satellite's potential, especially NGSO constellations, to help meet domestic connectivity goals, given its ability to reach remote areas that are under- or unserved by terrestrial networks (OECD, 2022[23]). For example, in Colombia in February 2022, the Ministry of

Information and Communication Technologies (MinTIC) issued a new regulatory regime for the provision of satellite services with the aim of encouraging the development of satellite connectivity in the country, particularly for hard-to-reach areas (MinTIC, 2022[34]).

29. Satellite innovations raise both technical and regulatory challenges, in particular regarding spectrum policy.[6] Regulating satellites' use of spectrum to manage radio interference takes place on two axes: the international level, coordinated by the ITU, and the national level, managed by regulatory authorities (OECD, 2022[23]). The ITU manages the process of international co-ordination and maintains the Master International Frequency Register to record the use of spectrum in space (ITU, 2022[35]). The national regulators oversee filings for proposed satellite systems and submit the requested frequencies to the ITU and are responsible for the authorisation of earth stations (OECD, 2022[23]). Another key regulatory question is whether the number of proposed satellites is feasible, when considering dangers related to space debris (OECD, 2022[23]).

High Altitude Platforms Systems (HAPS)

30. High Altitude Platforms Systems (HAPS) can be described as flying base stations or network nodes that operate in the stratosphere 20 km above the ground (ITU-R, 2020[36]).[7] They show promise to potentially bridge connectivity divides in rural and remote areas (OECD, 2021[37]). Their cell radius can be up to 100 km, compared to 8 km in rural areas for IMT 2020,[8] creating a cell area equivalent to the city of Paris (1 000 km^2) (ITU-R, 2022[38]).[9] HAPS have recently become more viable due to technological advances in energy efficiency, among other factors (ITU, 2022[39]).[10] Namely, developments in HAPS technologies may enable High Altitude IMT Base Stations (HIBS) -or "HAPS as IMT base stations" as labelled by the ITU-, bringing them a step closer of providing a future solution to connect the unconnected (RSPG, 2021[40]).

31. Given that HAPS are flying objects, they are subject to aviation regulation besides spectrum regulation. They can be lighter than air (LTA), like balloons, or heavier-than-air (HTA), like motorized gliders. As the wind speed is less intense in the stratosphere compared to lower altitudes, HAPS can maintain their position in the higher airspace consuming less energy. Another advantage is their large coverage area for mobile connectivity (Araripe d'Oliveira, Cristovão Lourenço de Melo and Campos Devezas, 2016[41]).

32. During the past decade, there have been several attempts to commercialise HAPS solutions to bridge connectivity divides, for example Google's Loon project, which was withdrawn in 2021 (Wired, 2018[42]; TechCrunch, 2021[43]). SoftBank, through its subsidiary HAPS Mobile, has worked in developing various parts of the HAPS ecosystem (HAPS Mobile, 2023[44]). A possible explanation for the limited use of aerial platforms so far is the technical challenges to integrate HAPS/HIBS in existing mobile networks as it could create interference. It also requires that frequency bands allocated for mobile communications do not have restrictions for the use of aeronautical mobile services[11] (ITU-R, 2022[38]).

33. The economic viability of aerial platforms also depends on spectrum availability for these services (OECD, 2022[23]). The World Radiocommunication Conference (WRC) 2023 will study possible new identifications for using HIBS as part of IMT networks (ITU, 2022[39]). HAPS/HIBS may be deployed more widely in the years to come as they could represent a cost-effective solution to provide connectivity to consumers in rural areas with limited or no access to communication services.

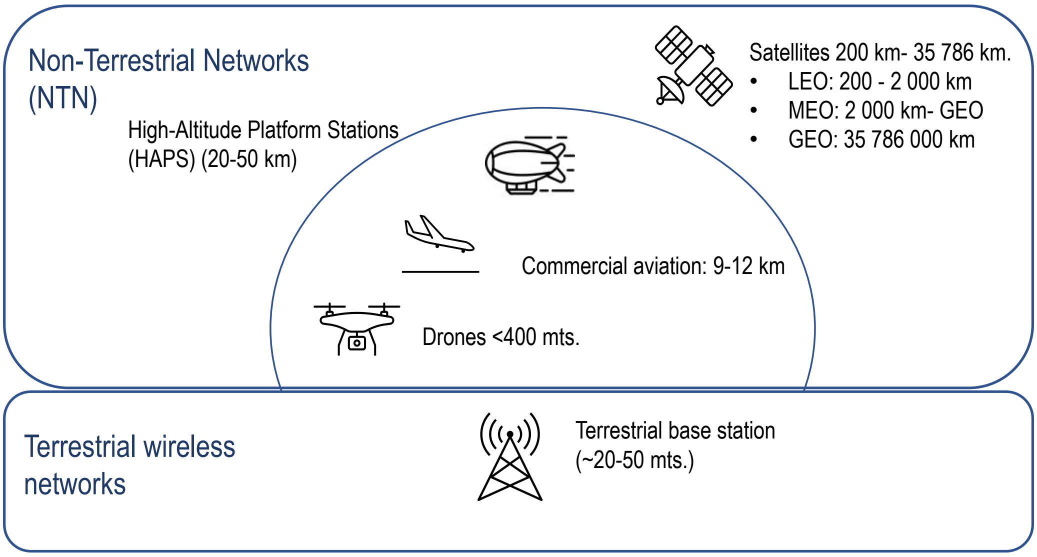
Section 3. Hybrid topologies for connectivity: Towards the ***integration of terrestrial and non-terrestrial network technologies***

34. Integrating different terrestrial and non-terrestrial wireless technologies constitutes the next step in expanding the connectivity ecosystem. Some broadband providers have started to explore ways in which satellite connectivity and other aerial communication technologies may complement existing terrestrial

networks to provide seamless communication with extended coverage, for example, through backhaul solutions (FierceWireless, 2021[45]), or through the development of hybrid satellite and ground networks for IoT applications (Spacenews, 2021[46]). For example, Deutsche Telecom (DT) claims to have achieved the world's first seamless 5G connection through different network layers to the stratosphere, space (Intelsat satellite network) and back to the mobile network (HT Group, 2023[47]).[12]

35. There is also an ambition in the communication industry to integrate terrestrial[13] (TN) and non-terrestrial networks (NTN)[14] within the scope of 6G projects (Figure 3). The aim is to support global, ubiquitous and continuous connectivity both in the ground as well for aerial users by integrating mobile terrestrial connectivity solutions with medium earth orbit (MEO), geostationary orbit (GEO), air-to-ground (A2G) networks and other aerial platforms. Integrated networks in three dimensions (3D) with a multi-layered architecture would combine the advantages of terrestrial and non-terrestrial networks (aerial platforms as well as satellite networks) to provide improved reliable, secure and robust connectivity for aerial and ground users through flexible and adaptive network architectures with multiple technologies (M. Ozger et al, 2023[48]). However, this integration is not without challenge as these technologies highly differ and do not provide the same performance features.

Figure 3. Towards vertical coverage: Convergence of terrestrial and non-terrestrial networks



Note: NTN=Non-terrestrial networks; TN= terrestrial networks.
Source: Own elaboration based on several on several sources, including: Ofcom (2021[16]), "Technology Futures – spotlight on the technologies shaping communications for the future", European Space Agency (2020[49]), "Types of orbits"; GSMA (2021[50]), "High Altitude Platform Systems: Towers in the skies".

36. The multi-layered architecture requires an interplay between the aviation, the terrestrial mobile communication sector and space industries. This calls for collaboration between different sectors that over the years have been competing for spectrum. The aviation community, for example, is facing a number of challenges as their legacy communication systems have experienced a fairly low rate of technology development and may have to deal with saturation in parts of the spectrum allocated for aeronautical services. At the same time, the aviation industry is advancing in its digitalisation, requiring higher efficiency in the use of airspace with connected aircrafts and the emergence of a wide variety of flying objects, like unmanned vehicles and electric vertical take-off and landing (eVTOLs) aircrafts such as "flying taxis", which could contribute to a more social and healthier environment in cities (Box 1) (EASA, 2022[51]). For example, in November 2022, France opened a hub for testing electric air taxis (Bloomberg, 2022[52]). Connectivity provided by terrestrial mobile communication operators can be an interesting solution for the aviation

sector, at least for communication services that are not mission critical and therefore could be offloaded from their legacy systems. This would be more cost effective compared to developing new propriety systems for the aviation sector (EASA, 2022[51]).

37. One example of recent ongoing research initiatives in this field is the European Union financed Single European Sky Air Traffic Management Research (SESAR) 3 Joint Undertaking, which aims to modernise Europe's air and ground Air Traffic Management (ATM) infrastructure and operational procedures to contribute to smarter, more sustainable, better connected and accessible air transport systems (SESAR 3, 2022[53]). Under that scenario, multi-layer broadband connectivity, e.g. in the form of future 6G networks, would need some form of integration with digitalised aviation systems. The expansion of communication services in airborne networks, along with future air urban mobility, drones, and other unmanned air vehicles, will drive the demand for a wide range of broadband communication services. The goal is to allow for limitless communication in and between terrestrial, airborne and satellite networks (Celtic-Next, 2022[54]).

Box 1. Flying taxis with electric vertical take-off and landing (eVTOLs) aircrafts for future transportation

An interesting application area in the ongoing research to integrate terrestrial and non-terrestrial networks are future airborne transport systems with urban air mobility with flying vehicles. Several manufacturers plan to launch commercial operations of electric vertical take-off and landing (eVTOLs) aircrafts, or "flying taxis", around 2025-2026 (NASA, 2020[55]).[15] The 2024 Paris Olympic Games aims to be the first to provide transportation with eVTOLs (FutureFlight, 2022[56]). The eVTOLs will be managed by a pilot on board, and could, in the longer run, be autonomous.

The eVTOLS will take-off and land at so called vertiports.[16] With the growing number of unmanned aerial vehicles (UAV) in the lower airspace, the management of the airspace is fundamental. This is done through unmanned aircraft system traffic management (UTM) (Federal Aviation Administration, 2023[57]). The UTM is complementary to the Air Traffic Management (ATM) system, which manage aircrafts in the airspace.[17] The eVTOLs will have advanced flight decks with a communication system that combines legacy aviation systems together with satellite and mobile communication networks. As such, different frequency bands allocated to mobile networks, satellite and aviation, will be needed.

Altogether, this development will require a fundamental shift of airspace regulation, which is currently underway. Moreover, to guarantee safe and reliable air traffic, security concerns of flying objects over cities need to be addressed. The current view within the aviation sector is that they will need to use commercial mobile networks to a large extent to handle growing demand for data transmission from aircrafts while relying on legacy aviation systems as fall-back solutions (EASA, 2022[58]).

38. The satellite industry is seeking to develop new business models and connectivity solutions. Although the inclusion of satellite in the 3GPP standard have led to more interaction between terrestrial mobile operators and satellite companies, more opportunities and partnerships may arise in the future. Examples of recent partnerships include Starlink with operators KDDI and Salt (KDDI, 2022[59]; Datacenter Dynamics [DCD], 2023[60]), and OneWeb with the operator VEON (OneWeb, 2023[61]). One driver paving the way for a more integrated ecosystem between terrestrial and non-terrestrial networks is developing user terminals that follow standardized radio interfaces, being able to connect on both terrestrial and satellite networks in a seamless way. The ongoing process for evaluating IMT-2020 Satellite Radio Interfaces being led by the ITU (ITU-R, 2022[62]) is important to follow by countries and industry players.

39. The combination of an aviation sector facing increased data demand, together with a satellite sector looking for new use cases, and a terrestrial communication sector eager to exploit new opportunities,

could establish a foundation for hybrid topology networks with an integration of terrestrial and non-terrestrial networks. However, this raises both technical and regulatory challenges for these technologies to be more impactful.

40. One main question relates to the actions policy makers could take to facilitate a constructive collaboration between three distinct sectors: space, aviation and mobile communications. Given existent regulatory structures, responsibilities are divided between different sector authorities.

41. Spectrum policy is also a key issue. The emergence of hybrid topology networks extending across national borders and stretching from the ground through the aerospace may call for a more dynamic access to spectrum and improved spectrum sharing.

42. Apart from physical security and safety issues for traditional aircrafts and other flying objects, the issue of digital security is of great concern for the next generation of wireless networks. This could also involve satellite communication and data processing in cloud solutions in the airspace.

43. Finally, this spotlight emphasised the technical developments of wireless networks seeking higher performance (in terms of bandwidth, lower latency, energy efficiency) and increased coverage. At the end of 2022, there were still 44% of the World's population "offline" (ITU, 2023[63]). The digital divide especially affects vulnerable segments of the population, such as rural and low-income households. As such, coupled with the promising technology advances shaping the connectivity ecosystem this next decade, it remains imperative to continue at pace with policy efforts to bridge connectivity divides.

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Notes

[1] With previous mobile generations, such as 4G and 5G, eight to twelve years elapsed between the time the “technology” vision was set, the technological standards agreed upon, until operators started with the first commercial deployments. For example, for 5G, the ITU-R Working Party 5D defined in 2012 the vision for IMT-2020 (5G), and the first commercial deployments started in April 2019, with many networks launching during 2020.

[2] The 3rd Generation Partnership Project (3GPP) unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC). 3GPP specifications cover cellular telecommunications technologies, including radio access, core network and service capabilities (3GPP, 2023[65]).

[3] Historically, radar or sensing systems were developed independently from mobile communication technologies. There is growing interest in merging these two technologies. Namely, the use of mmWave or terahertz frequencies used in combination with massive MIMO and machine learning techniques may enable a finer spatial resolution to detect even subtle movements, such as finger gestures. Communication systems using terahertz spectrum may allow for very high throughput and very low latency, providing an opportunity to conceive joint communication, sensing and positioning systems. Thus, it is being regarded as a promising technology for future 6G systems (Ofcom, 2021[16]).

[4] This would enable a move from wide beams to multiple smaller spot beams and concentrate power on a smaller area, increasing link performance, as well as making it possible to reuse spectrum multiple times, increasing the amount of capacity per satellite.

[5] 3GPP Release 17 (frozen in 2022), offers two forms of satellite communications to mobile devices: IoT-NTN, which will provide low data-rate narrow band communications, and NR-NTN, which will provide broadband communications for high data-rate communications, such as video calls (Forbes, 2023[28]).

[6] Different stakeholders are currently engaging on this topic, such as the European Conference on Postal and Telecommunication Administrations (CEPT) (CEPT, 2022[68]).

[7] High Altitude Platform Stations (HAPS) are defined by the ITU’s Radio Regulations as radio stations located on an object at an altitude of 20-50 kilometres and at a specified, nominal, fixed point relative to the Earth (ITU-R, 2020[36]).

[8] IMT-2020 are the requirements issued by the ITU-R in 2015 for 5G networks, devices and services.

[9] The idea of using platforms in the stratosphere to provide communication services goes back to the end of the 1960s when the first experimental projects were initiated. R&D on aerial platforms, given different labels over time, have been ongoing ever since then (Araripe d’Oliveira, Cristovão Lourenço de Melo and Campos Devezas, 2016[41]).

[10] High Altitude Platform Stations (HAPS) are defined by the ITU’s Radio Regulations as radio stations located on an object at an altitude of 20-50 kilometres and at a specified, nominal, fixed point relative to the Earth (ITU-R, 2020[36]). The initial definition of “High Altitude Platform Station” (HAPS) was established at the World Radio Conference (WRC) 1997 and spectrum were allocated in the 47-48 GHz-band (ITU-R, 1997[66]). It has later been redefined by ITU.

[11] A mobile service transmitting signals between aeronautical stations and aircraft stations.

[12] The European Space Agency and DT agreed in a memorandum of understanding (MoU) to work together on the hybrid networks of the future, for more resilient and secure connectivity solutions (HT Group, 2023[47]).

[13] The ITU Radio Regulations defines terrestrial radiocommunication as any radiocommunication other than space radio communication or radio astronomy. See ITU Radio Regulations, article 1, section 1 "General terms", Sub-section 1.7 (ITU-R, 2020[36]).

[14] According to 3GPP, NTN refers to networks, or segments of networks, using an airborne or spaceborne vehicles for transmission (3GPP, 2018[67]).

[15] For example, companies working on developing eVTOLS include Airbus SE in France, Archer Aviation in the United States, Joby Aviation in the United States, Lilium in Germany, Vertical Aerospace in the United Kingdom and Volocopter in Germany.

[16] The European Union Aviation Safety Agency (EASA) defines a vertiport as "an area of land, water, or structure used or intended to be used for the landing and take-off of eVTOL aircraft".

[17] According to the European Union Aviation Safety Agency (EASA), an "Air traffic management (ATM) aggregation of the airborne and ground-based functions (air traffic services, airspace management and air traffic flow management) is required to ensure the safe and efficient movement of aircraft during all phases of operations".