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Executive Summary

Virtual worlds (VW) are meant to have a significant economic and social impact by transforming the way online content and applications are experienced by means of immersive environments. VW are part of a wider technological change: the transition towards Web 4.

This BEREC Report aims at contributing to the knowledge sharing and exchanges with relevant stakeholders and EU institutions focusing on implications to the electronic communications sector and the state of the art of network developments aimed to enable immersive technologies. It builds on previous BEREC's work including in particular the BEREC high-level position on artificial intelligence and virtual worlds[1] provided as a contribution to the call for inputs[2] on competition in generative AI and Virtual Worlds issued in 2024 by the European Commission (EC).

The report is framed in the **Introduction Chapter** by providing a definition for VW, based on its key characteristics (immersivity, synchronicity, persistence, unity and mass creation), and for the broader concept of Web 4. This chapter follows with acknowledging the general challenges posed by VW/Web 4 (interoperability, environmental impact, users' rights and governance and jurisdiction matters).

Chapter 2 provides some concrete examples of use cases to illustrate how immersive technologies could transform everyday activities and industries, and the electronic communications providers' role to enable them.

Chapter 3 describes the connectivity challenges faced to enable VW and the network upgrades being developed aimed at solving some of these problems in the future generations of network connectivity (e.g. Wi-Fi 7/8, 5th Advanced Generation Fixed Networks and 6G). BEREC notes in this regard that many applications will push the limits of current networks, requiring unprecedented bandwidth at extremely low latency to function properly. Supporting these requirements at scale will likely necessitate significant investments in infrastructure (fibre, 5G/6G, edge and cloud), as well as developments in network management and orchestration.

Chapter 4 assesses the potential role of electronic communication providers in the provision of VW/Web 4 services, as well as any possible future profit streams and incentives for related investments, i.e. provision of advanced connectivity, edge computing, and new or enhanced electronic communication networks and services (ECN/S), e.g. sensing-networks or efficiencies resulting from VW solutions for connectivity such as network digital twins. While observing opportunities for (ECN/S) providers, there are uncertainties around the market structures and business models for VW/Web 4 and also the complexity of the VW ecosystems, meaning that operators must interwork with a large group of different providers in related fields (e.g. device manufacturers, platforms or cloud providers).

Finally, **Chapter 5** examines the potential electronic communications regulatory challenges that may arise in relation to VW/Web 4. BEREC notes that in-depth understanding of the relevant services, business models and their likely evolution is a necessary precondition for any potential

[1] BoR (24) 68, Berec High level position on artificial intelligence and virtual worlds
[2] See https://ec.europa.eu/commission/presscorner/detail/en/IP_24_85

regulatory adaptation to preserve public policy objectives, including end-user protection, effective competition, and the promotion of investment and innovation. At this stage, regulatory predictability, complemented by public policy instruments and cooperation models, can act as a key enabler of long-term investment in digital infrastructures. BEREC underscores the importance of openness and interoperability across the digital ecosystem as well as the role of regulators in monitoring and clarifying the application of the existing regulatory framework to VW/Web 4-related connectivity and services. The chapter also considers the challenges that VW/Web 4 may pose for digital inclusion, particularly with regard to coverage and affordability. The timely availability of suitable spectrum bands and their efficient use is critical to enable the provision of the services and will be closely followed by BEREC. Finally, the analysis addresses potential competition risks across the ecosystem – from gatekeeper power to exclusionary partnerships – and the corresponding implications for connectivity and related services.

1. Introduction

The emergence of virtual worlds and Web 4.0 (VW/Web 4) services is expected to profoundly impact electronic communications networks and services (ECN/S) as acknowledged by the EU institutions[3].

The term "virtual worlds" (often used alongside "metaverse"[4]) has been defined in various ways[5], and the terminology continues to evolve with the technology. In the Communication An EU initiative on Web 4 and virtual worlds: a head start in the next technological transition, the European Commission (EC) defined VW as "*persistent, immersive environments, based on technologies including 3D and extended reality (XR), which make it possible to blend physical and digital worlds in real-time, for a variety of purposes such as designing, making simulations, collaborating, learning, socialising, carrying out transactions or providing entertainment*".

Table 1 below outlines the characteristics of VW as identified across academia and stakeholders[6].

Table 1 - Key characteristics of virtual worlds

Immersivity	Users feel "inside the digital environment ", with a sense of absorption in the activity or environment. This sensory engagement is enabled (to different degrees) by technologies like augmented reality (AR), virtual reality (VR), and mixed reality (MR), which are encompassed under the concept of extended reality (XR)[7].
Synchronicity	In VW users experience real-time interaction with other users (including communication) and, also, with the environment. This creates a sense of being in a shared common environment.
Persistence	VW continue to exist and evolve even when users are disconnected from them, and such changes may impact users upon their return.
Unity	A fully "unified" experience with seamless interconnections between VW is considered key to allowing users to move identities, data, currency, and items across platforms. However, unity requires interconnection and interoperability among platforms and is associated with a possible mature stage of the development of VW.
Mass creation	In VW users can create or modify content, adding new features and applications that may modify the environment. Thus, some academic contributions also emphasize the feature of mass content creation as a key identifier of VW[8].

[3] For example, in 2023, the EC published the COM (2023) 442 COMMUNICATION: An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition and in 2024 the European Parliament adopted an IMCO own-initiative report on Virtual worlds focusing on the opportunities, risks and policy implications for the single market
[4] For example, see the definition of metaverse included in "Exploring the metaverse: opportunities and challenges" (2023), ITU (Focus group on metaverse): "*metaverse and multiverse refer to virtual universes with close connections to and interactions with the real world, with the support of a set of digital technologies and information and communication technologies (ICTs), including AI, IoT, digital twin and blockchain. A metaverse can be considered as a collective space or unified platform, while the multiverse (metaverses) has several integrated digital platforms and ecosystems that interact*". See also Citiverse use case taxonomy Overview, definitions, p. 17, or the definitions quoted in the document "A European Regulatory Framework for the Metaverse" (2024) produced by the Metaverse Chair from the University of Alicante.
[5] See a discussion in section 1.1" in 2023 CEP Policy Brief "EU-metaverse strategy: web 4.0 & virtual worlds" entitled "Confusing Terminology".
[6] See for example "An immersive technologies policy primer", OECD, 2025.
[7] See different examples of XR in these videos: (3379) National Geographic Augmented Reality experience by INDE - YouTube, https://youtu.be/EDtAy4OovB4, Learning Science in VR.
[8] See CERRE's 2024 report "Emerging virtual worlds: implications for policy and regulation", which defines virtual worlds as "an immersive, synchronous, persistent and unified 3D user experience that enables mass content creation".

Web 4 is a broader concept than VW, encompassing a wider array of technologies, and defined by the EC's Communication as "*the expected fourth generation of the World Wide Web. Using advanced artificial and ambient intelligence, the internet of things, trusted blockchain transactions, virtual worlds and XR capabilities, digital and real objects and environments are fully integrated and communicate with each other, enabling truly intuitive, immersive experiences, seamlessly blending the physical and digital worlds*". In essence, this describes the expected next stage of the internet evolution – where interoperability across networks and platforms enables greater freedom of choice for users.

For the purposes of this report, VW refers to persistent, immersive 3D digital environments, and Web 4 denotes the broader ecosystem integrating AI, IoT, XR, blockchain and virtual worlds into an immersive, intelligent internet – and the ecosystem referred to as 'VW/Web 4'.

VW are seen as an important component of the envisioned Web 4 transition, but they are currently at an early "birth" stage and siloed, since broad interoperability has yet to be developed. Indeed, some commentators[9] foresee VW to develop through three phases. Following the "birth stage", an "infancy phase" is predicted and described as a network of interconnected and interoperable VWs in which user elements like identities, avatars, data, and assets can seamlessly move across platforms. The final "maturity phase", would be one where there is a complete integration of VW within the Web 4 environment, this being a single environment, although with uncertain characteristics at this point.

Currently, VW/Web 4 are at the crossroad of many broad challenges typical of digital ecosystems (summarized in **Table 2**). At the same time, there are specific challenges tied to the ECN/S sector itself, which are examined in detail throughout the report – particularly in **Chapter 3** and **Chapter 5** (regulatory challenges).

Table 2 - General challenges posed by VW/Web 4

Interoperability	Infrastructures built on open and interoperable protocols are a great enabler for an open ecosystem, user rights, competition and innovation. Without open standards and interoperability, end-users face vendor lock-in. For example, if there are no effective data portability mechanisms, they can't migrate from one virtual environment to another while retaining access to their personal data and digital assets. Similarly, they can't communicate with users operating in non-compatible digital environments. Businesses, in turn, face high switching barriers between providers and cannot thrive in a competitive environment. Standardization efforts are already underway with several dedicated bodies working to define relevant standards; however, progress is hampered by the complexity of the multilayered technical stack and could risk insufficient participation of all stakeholders across the ecosystem.
Environmental impact	VW/Web 4 are expected to have significant environmental cost, in particular associated to the disposal of terminal equipment such as VR headsets or sensors. ITU and IEEE are working on specific methodologies for a precise assessment of the metaverse environmental footprint, guiding future developments.[10] In line with the

[9] Ibid.

[10] See e.g. Technical Specification ITU FGMV- 50, "Methodology of assessment of GHG emissions of metaverse", 06/2024. With specific regard to mobility systems, see IEEE "IC23-011 Impact Assessment Framework for Sustainable Mobility Systems".

	European strategy regarding carbon emissions and environmental footprint, this should be monitored closely by competent authorities.
Users' rights	The user's rights must be protected to ensure everyone benefits from VWs: the developments must be user-centric, considering accessibility, data protection, privacy concerns and inclusion.
Governance and jurisdiction matters	The EU digital regulations provide already a toolkit to support a VW/Web 4 regulatory framework. However, efficient coordination aimed at consistent implementation at EU level may be challenging due to the decentralised nature of this ecosystem.

The Report follows this structure: **Chapter 2** presents key use cases of VW/Web 4. **Chapter 3** analyses connectivity developments. **Chapter 4** discusses potential challenges and opportunities for the electronic communications sector and its players. **Chapter 5** outlines regulatory considerations for investment and openness. In order to streamline the document, the body of the report includes the key considerations that are complemented by more in-depth analysis and detailed information in the **Annexes I to IV** as follows:

CHAPTER	RELATED ANNEX	MAIN ISSUES COVERED
Introduction	ANNEX I - general challenges	Develops on the general challenges posed by VW/Web 4.
Chapter 2 – Use cases	ANNEX II - selected use cases and their impact on the electronic communications sector	Describes in further detail the use cases, network implications and potential regulatory challenges.
Chapter 3 – Connectivity developments	ANNEX III – network performance	The current network performance section describes the performance thresholds that VHCN shall be able to achieve at the current state of the art. The network performance requirements for VW section presents the results of the desk research on network performance requirements for VW mainly focus on three parameters: impact on data traffic; bandwidth and latency.
	ANNEX IV - upcoming network developments	Describes further some of the main upcoming ECN developments relevant for VW evolution in relation to Wi-Fi, fixed and mobile networks.

2. Use cases

The VW/Web 4 paradigm aims at giving rise to a diverse set of innovative use cases that blend digital and physical environments[11]. **Table 3** presents a sample of these use cases, which are further developed in **ANNEX II** and referenced in the following chapters.

[11] See for instance *Citiverse Use Case Taxonomy Overview - Use Case Identification Track*.

Table 3 – Examples of use cases and implications for ECN/S (operators)

Use Case	Description	Network Impact	Key Challenges	Additional Observations
Urban digital twins[12] **("Cityverse")**	Real-time city-scale digital replicas integrating IoT and 3D data for urban management, planning, and disaster response.	Very high bandwidth, ultra-low latency; multi-access edge computing (MEC) for local responsiveness.	Open standards; data governance; privacy/security; investment in infrastructure.	Key tech[13]: MEC. **Operator role**: provision of dedicated network slices, Application Programming Interfaces (APIs) (e.g., geolocation).
Industrial Virtual Worlds (digital twins)	Virtual factory and equipment models enabling predictive maintenance, optimization, and remote operations.	Ultra-reliable low latency (URLLC); critical private 5G and edge computing deployments.	Spectrum policy; interoperability (between private and public networks); cybersecurity.	Key tech: Private xG, Time-Sensitive Networking (TSN), network slicing. **Operator role:** Industry-focused connectivity solutions, secure Network-as a-Service (NaaS) orchestration.
Immersive collaboration & telemedicine	Real-time AR/VR collaborative workspaces and remote medical interventions.	High bandwidth, very low latency, critical reliability (zero downtime required).	Quality of Service (QoS); stringent privacy and data protection (GDPR); infrastructure/coverage (and affordability) to prevent digital divide.	Key tech: network slicing, dynamic QoS APIs, edge processing. **Operator role:** dedicated slices/private networks for critical services.
Immersive entertainment (gaming/ events)	VR/AR gaming and large-scale virtual live events, attended via avatars.	Intensive network load; extreme demands for low latency/high bandwidth; scalability essential.	QoS; consumer transparency on network performance.	Key tech: Edge caching, multicast/broadcast capabilities. **Operator role**: specialized QoS tiers, API monetization for content providers.
Tele-operated mobility (vehicles/ drones)	Remote control of vehicles and drones via VR/AR interfaces, enabling new logistics, public safety, and autonomous transport use cases.	URLLC; continuous large throughput for sensor/video data streams.	Coordination between NRAs and transport regulators (e.g. seamless inter-network roaming/handover).	Key tech: xG URLLC, multi-network connectivity. **Operator role**: specialized connectivity lanes, roaming/handover APIs exposure[14]).
Immersive Education & Training	AR/VR interactive platforms for educational institutions and professional	Wide availability of high bandwidth and low latency; capability for large-scale	Infrastructure/coverage (and affordability) to prevent digital divide; interoperability (of educational platforms);	Key tech: Nationwide broadband, edge computing, adaptive QoS APIs.

[12] According to the Digital Twin Consortium, a digital twin is an integrated data-driven virtual representation of real-world entities and processes, with synchronized interaction at a specified frequency and fidelity. See Definition of a Digital Twin.
[13] While these key technologies are currently considered particularly suitable for these use cases, this doesn't preclude the role that other technologies have.
[14] For example, CAMARA (GSMA-led project standardizing a common set of network APIs, https://camaraproject.org/), NEF (Network Exposure Function) and CAPIF (Common API Framework for 3GPP Northbound APIs).

	training, enabling virtual classrooms and realistic simulations.	synchronized interactions.	stringent data privacy enforcement.	**Operator role**: tailored educational connectivity solutions, dynamic performance management.

These examples show that immersive technologies (AR/VR, digital twins, etc.) could transform everyday activities and industries, creating major opportunities for ECN/S operators beyond traditional connectivity (see **Chapter 4**)[15]. Across domains – from city management to entertainment to healthcare – VW/Web 4 applications will depend on ECN/S not just for basic connectivity, but as platforms delivering ultra-fast, low-latency, highly reliable data services. ECN/S operators are therefore posed to play a fundamental role in enabling these experiences by providing ubiquitous high-capacity networks, integrating edge computing, and ensuring the necessary quality-of-service (see **Chapter 3**). This trend also creates new business opportunities for operators (e.g. offering specialized network slices or exposing APIs for immersive services) but will require them to significantly upgrade and adapt their infrastructure (see **Chapter 4**).

At the same time, these emerging use cases introduce new challenges for networks and regulators. Building on these challenges and use cases, the next chapters examine connectivity, market and regulatory challenges in more detail.

3. Connectivity developments

3.1. Connectivity challenges for supporting virtual worlds and Web 4

Blending the physical and the VWs in a continuous and persistent manner requires upgraded digital infrastructures capable to collect, transport and process enormous volumes of data with extremely low latency. Even as capacities of networks and digital infrastructures improve, significant challenges persist. For example, for synchronicity, connectivity with sufficient quality needs to be ensured for all the users interacting in a shared immersive experience at the same time. Similarly, difficulties arise when the data to be processed, rendered, and synchronized exponentially increases with the number of connected users[16].

Meeting these performance demands – to support immersive experiences, achieving real-time responsiveness – will require not only networks providing higher bandwidths and lower

[15] Currently, the gaming industry, a central driver of the VW/Web4's evolution, is gaining strong momentum and merits special attention. Beyond their traditional role as connectivity providers, ECN/S operators are increasingly exposing network capabilities to support real-time and cross-platform gameplay, while partnering with cloud-gaming platforms, device manufacturers, edge/cloud providers and e-sports organisers. This trend is accelerating worldwide, including in Europe, where leading operators have already introduced gaming-focused bundles and partnerships. See also **Annex II**.

[16] In *The Metaverse and How It will Revolutionize Everything*. Matthew Ball (2022), Ball develops on the connectivity challenges of VW related to synchronicity and concurrency. Synchronicity, as persistent and interactive environments where all users can simultaneously impact the VW, entails that a single user falling out of synchronization impacts the entire collective experience. Concurrency, as the amount of data to be processed, rendered, and synchronized per unit of time, exponentially increases depending on the number of connected users. In light of these challenges, Ball concludes that we are far from being able to replicate the density and flexibility of the "real world", and it is likely to remain impossible for some time.

latencies[17], but also additional digital infrastructures (such as edge computing nodes) to enable fast data delivery and processing[18]. However, as the Digital Decade report reflects, there is still slow investment on edge nodes[19]. Ultimately, fulfilling the VW/Web 4 vision entails further decentralization of network architectures and converging communication, computing and caching resources into integrated 3C networks[20]. Academic discussions[21], and ETSI[22], suggest that VW applications will push networks to evolve from a purely "capability-oriented" model to a more "service-oriented" collaborative framework for all the technologies involved. Additionally, these infrastructure developments can be complemented with higher-layers solutions to optimize traffic[23] as well as AI-driven network management and enhanced cross-domain orchestration).

Consequently, ECN infrastructures should adapt by incorporating next-generation technologies (e.g. 5G-Advanced/Standalone and, in a longer term, 6G). Operators can leverage innovations such as network slicing (creating virtual network segments tailored to specific requirements of applications) and install edge computing facilities closer to end-users to satisfy strict low-latency requirements. Progress toward more programmable, automated, and cloud-native network architectures will be critical to meet the anticipated demands of VW/Web 4.

Today's networks cannot yet meet all the performance requirements of a fully developed VW environment. Nevertheless, the evolution may be incremental, with some initial steps towards this concept emerging as *"proto virtual worlds"* or through advances in different enabling technologies, forming the building blocks of VW connectivity. Moreover, network performance requirements will also differ by use case – not every VW/Web 4 application will pose the same level of challenge.

Annex III provides insights into the performance levels typically expected from today's state-of-the-art networks. In particular, the performance thresholds for Very High-Capacity Networks (VHCN) at peak time – as defined in the BEREC Guidelines on VHCN[24] – are used here as a benchmark for advanced connectivity.

[17] As noted below, latency requirements could require up to 1 millisecond target. The challenges that this entailed (including, for example, the limits imposed by physics such as the light speed) have further described by S. Panwar. Breaking the Latency Barrier (2020) who proposes the solution of further edge computing deployment.
[18] For instance, transmission delays must be minimized to avoid degrading the user experience (e.g. preventing cybersickness – motion sickness induced by VR).
[19] https://digital-strategy.ec.europa.eu/en/library/state-digital-decade-2025-report.
[20] In the 2024 White Paper - How to master Europe's digital infrastructure needs? the EC uses the term "3C Network" as Connected Collaborative Computing Networks. Although the EC proposition seems broader, it makes reference as well to the integration of computing resources with network capacities to enable embedded and ubiquitous computing and distributed network elements. The concept of computing continuum as an enabler for VW/Web4 bringing together transmission, storage and computing is also mentioned by the EC in its *Staff Working Document: information, insights and market trends on web 4.0 and virtual worlds* (2023).
[21] Cai, Y., Llorca, J., Tulino, A. M., & Molisch, A. F. (2022). Compute- and Data-Intensive Networks: The Key to the Metaverse. *IEEE*, 1–8.
[22]https://www.etsi.org/newsroom/blogs/entry/etsi-released-the-f5g-advanced-generation-definition-promoting-the-evolution-of-f5g
[23] For instance, advanced data compression techniques, delay-based and rollback netcodes or lower AR/VR data transmission by means of narrower field of view (FOV) instead of 360º.
[24] https://www.berec.europa.eu/en/all-documents/berec/regulatory-best-practices/guidelines/berec-guidelines-on-very-high-capacity-networks

Also, BEREC's Report on the IP Interconnection Ecosystem[25] observes network developments that help coping with increasing traffic while enhancing QoS. For example, IP traffic is increasingly being localized (regionalised) to meet low-latency requirements, which in turn has led to the deployment of content delivery networks (CDN) caches inside Internet access providers' networks and at Internet exchange points (IXPs). Placing content "on-net" in this way reduces backbone traffic and improves latency.

Annex III also reviews various studies on the networks requisites to deliver VW/Web 4 services and provide some hypothetical estimates mainly focusing primarily on three parameters: impact on data traffic, data rates, and latency. While there is broad consensus networks will need to meet stricter performance requirements than today's, the specific QoS thresholds differ in the studies consulted by BEREC. This is because the studies examine different scenarios/use cases; some focus on AR/VR use cases or early "proto" VW scenarios, while others take a more forward-looking approach and consider even more demanding applications (e.g. advanced sensing/haptic or holographic communications). **Table 4** below provides examples of these findings by comparing the latency requirements for different possible use cases, based on the studies consulted by BEREC[26].

Table 4 - Latency requirements on different use cases

USE CASE	ESTIMATED LATENCY REQUIRED
ROUND-TRIP LATENCY FOR VIDEO CALLING/CLOUD GAMING	75-150ms
LATENCY FOR MULTI-PLAYER COMPLEX GAMES	Sub 30 ms
"STANDARD" METAVERSE APPLICATIONS/VR – E.G. URBAN DIGITAL TWINS ("CITYVERSE")	Sub 20 ms / 20-25 ms
TRULY IMMERSIVE METAVERSE EXPERIENCES, VR AND AR – E.G. IMMERSIVE ENTERTAINMENT (GAMING/EVENTS) OR IMMERSIVE COLLABORATION & TELEMEDICINE	Sub 12 ms / Sub 13 ms
INTERNET OF SENSES – E.G. INDUSTRIAL VW (DIGITAL TWINS)	Sub 10 ms
AUTONOMOUS VEHICLES – E.G. TELE-OPERATED MOBILITY (VEHICLES/ DRONES)	2 ms
HAPTIC AND HOLOGRAPHIC COMMUNICATIONS	1 ms[27]

[25] See https://www.berec.europa.eu/en/all-documents/berec/reports/berec-report-on-the-ip-interconnection-ecosystem. See also, BEREC Report on the entry of large content and application providers into the markets for electronic communications networks and services.
[26] These examples, coming from the literature review, are provided as a general proxy of the increased network demand for VW/Web4. Those estimates come from different sources that may follow diverse methodologies and assumptions. Moreover, some are just hypothetical as regard to future services.
[27] The latency requirement of 1ms was given in the context of tactile applications, with remote surgery given as use case. Reasons given for these requirements are lagged responses and motion sickness, which occur at higher latencies (see Cai, Yang et al., 2022. ‚Compute- and Data-Intensive Networks: The Key to the Metaverse'. https://arxiv.org/abs/2204.02001. Also, latency requirements of 1ms are expected for holographic communications according to Uddin, Muddin et al., 2024. ‚Exploring the convergence of Metaverse, Blockchain, and AI: A

Source: BEREC elaboration based on different sources[28]

3.2. Network Developments

Table 5 outlines several network developments that would be required for the provision of VW/Web 4, organized by network type (more detailed information can be found in **Annex IV**).

Table 5 - Future ECN developments

WI-FI	**Wi-Fi 7 (Standard 802.11be)**		
	Features	Ultralow latency, high data rates, and support a greater number of connected devices to enable the provision of real-time applications and XR.	
	Timing	Released in 2025	
	Wi-Fi 8 (Standard 802.11bn)		
	Features	Aiming at industrial applications, it could support data rates of up to 100 Gbps and further communications and sensing integration.	
	Timing	To be released in 2028	
FIXED	**5th Advanced Generation Fixed Networks (F5G-A)**[29]		
	Features	Enhancement of fixed connectivity in six dimensions: i. Enhanced Fixed Broadband; ii. Real time Resilience Link; iii. Guaranteed Reliable Experience; iv. Optical Sensing and Visualization; v. Full-Fibre Connection and vi. Green Agile Optical network.	
	Timing	To be released in 2030	
MOBILE	**6G (Standard IMT-2030)**		
	Features	Enhancement of mobile connectivity in six dimensions: i. Immersive Communication; ii. Hyper Reliable and Low-Latency Communication; iii. Massive Communication; iv. Ubiquitous Connectivity; v. Artificial Intelligence and Communication and vi. Integrated Sensing and Communication	
	Timing	To be released in 2030	

comprehensive survey of enabling technologies, applications, challenges, and future directions' https://wires.onlinelibrary.wiley.com/doi/full/10.1002/widm.1556

[28] List of sources: Metaverse and Money. Decrypting the Future (2022) Citi; N. Sehad, L. Bariah, W. Hamidouche, H. Hellaoui, R. Jäntti and M. Debbah, "Generative AI for Immersive Communication: The Next Frontier in Internet-of-Senses Through 6G," in IEEE Communications Magazine, vol. 63, no. 2, pp. 31-43, February 2025,; Y. Cai, J. Llorca, AM Tulino, AF. Molisch "Compute- and Data-Intensive Networks: The Key to the Metaverse" (2022); Network Requirements for Metaverse Services. Metaverse standards forum.; S. Panwar. Breaking the Latency Barrier (2020); Uddin, Mueen & Obaidat, Muath & Manickam, Selvakumar & Laghari, Shams Ul Arfeen & Dandoush, Abdulhalim & Ullah, Hidayat & Ullah, Syed Sajid. (2024). Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 14. 10.1002/widm.1556.

[29] Networks today are migrating to XG(S)-PON delivering 1Gbps connectivity. F5G-A is based in further upgrades to 50G-PON aiming to provide symmetric 10 Gbps. VW/Web4 are among the reference services it aims to provide.

The standardization efforts reveal several propositions and trends that are common across all network types to support the provision of VW/Web 4 services.

3.2.1. Virtualization and cloudification

BEREC has previously highlighted[30] the possibilities that network virtualization and cloudification offer for improving network management, flexibility and scalability. In particular, virtualized networks have the possibility to expose the network capabilities in a programmable way and be tailored to enable new services via Network-as a-Service (NaaS) solutions/platforms.

As mentioned in the BEREC Report on Cloud and Edge Computing Services, ECN/S providers are developing common APIs to be exposed to third parties (developers) that they can use to leverage enhanced network features and capabilities to design and deliver (their own) solutions. Some of these APIs can be useful in the context of VW/Web 4, for example, those for QoS management or edge node discovery under the CAMARA project[31]. Latest developments explore the use of generative AI to help application developers access network intelligence more easily, essentially bridging gaps between applications and these network API[32].

Virtualization and cloudification also underpin the provision of network slicing, i.e. logically partitioning the network into slices, each optimized to specific QoS parameters. While acknowledging that these capabilities are relevant for the provision of stringent use cases, including VW/Web 4, reference is made to these previous reports to avoid repetitions.

3.2.2. Integrated 3C Networks

One way to reduce latency is by processing data closer to the end-user – for example, using edge computing, or even on the (end)device or other local infrastructures[33].

According to BEREC's Report on Cloud and Edge Computing Services, edge computing is particularly well-suited for services such as vehicle-to-everything (V2X) communications, AR applications, real-time video analysis, location-based services, or optimized local content

[30] Among others, for instance, the BEREC Report on the 5G Ecosystem BoR (22) 144 or the BEREC Report on Cloud and Edge Computing Services BoR (24) 136.
[31] See https://camaraproject.org/api-overview/. For further detail on the CAMARA and related interoperability initiatives see also **Annex I**, in particular table 6.
[32] See for example, https://mobileecosystemforum.com/2025/09/11/is-chatgpt-killing-gsma-open-gateway/ or https://youtu.be/iWTcEn5H0UQ?si=sExihYT1Eo2uFk-n.
[33] For example, as Matthew Ball describes (The Metaverse and How It will Revolutionize Everything. Matthew Ball (2022), most VW today make use of a hybrid local/cloud streaming data model in which the "core game" is preloaded, but several times as much data are sent on an as needed basis. Another more forward-looking example of hybrid local/cloud model could be the use of opportunistic offloading in the context of distributed IoT/ industrial IoT (IIoT) devices connectivity, for example, T. M. Fernández-Caramés and P. Fraga-Lamas, "Forging the Industrial Metaverse for Industry 5.0: Where Extended Reality, IIoT, Opportunistic Edge Computing, and Digital Twins Meet," in IEEE Access, vol. 12, pp. 95778-95819, 2024, doi: 10.1109/ACCESS.2024.3422109.

distribution for both consumers and industry verticals. Also, the EC estimates that in the coming years generated data will increasingly be processed at the network edge[34].

Such (robust) edge infrastructure requires, in turn, having high-quality connectivity in place to deliver (VW/Web 4) services with an adequate QoS. The Academia and standardization bodies are also examining how connectivity can facilitate "edge-to-cloud" workload orchestration and closer integration of computing and network resources, improving efficiency and user experience. They propose that communication networks evolve towards tightly integrated computing-caching-communication (3C) systems. Such concept entails a wide range of distributed network elements (end devices, access points, edge servers, cloud nodes, etc.) cooperating – each contributing resources and handling aspects of routing, storage, and processing – to deliver services seamlessly[35]. Following a similar approach, the ITU has introduced the concept of computing power network (CPN)[36] as networks optimized for the distribution, coordination, and scheduling of computing, storage and network connectivity resources.

The ETSI F5G[37] vision likewise stresses the need to adapt communication networks to interconnect users with distributed computing resources. ETSI underlines that integrating computing, storage, and communications requires careful orchestration of all resources and infrastructure components. The network must be able to dynamically scale each component and to provide the resource functionality needed to react to changes in demand and location of the services. For the most stringent cases, this CPN approach may be combined with Time-Sensitive Networking (TSN) or deterministic networking (Detnet) to ensure highly reliable, guaranteed transmission.

Looking ahead to 6G[38], the ITU envisages ubiquitous computing disseminated across future (IMT-2030) networks to enable efficient utilization of resources and optimal workload placement, as well as to scale and manage the infrastructure to run new applications. The EU's Smart Networks and Services Joint Undertaking (SNS JU) white paper on 6G architecture further develops on the importance of a seamless "deep edge-edge-cloud" continuum for 6G[39], in particular, the seamless convergence of network slicing, multi-access edge computing (MEC), and cloud-edge continuum, to unlock the full potential of 6G. Contributors to this paper describe a holistic approach to traffic handling, where networks are aware of each sub-component's latency characteristics (from variable wireless links to edge-compute tasks and buffering points), and to an end-to-end

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[34] See https://digital-strategy.ec.europa.eu/en/policies/cloud-computing. "*Whereas cloud computing happens mostly in large data centres today, by 2025 this trend will reverse: 80% of all data is expected to be processed in smart devices closer to the user, known as edge computing".*

[35] Cai, Y., Llorca, J., Tulino, A. M., & Molisch, A. F. (2022). Compute- and Data-Intensive Networks: The Key to the Metaverse. *IEEE*, 1–8.
[36] Recommendation ITU-T Y.2501. Computing power network – Framework and architecture. ITU (2021).
[37] See https://www.etsi.org/newsroom/blogs/entry/etsi-released-the-f5g-advanced-generation-definition-promoting-the-evolution-of-f5g.
[38] See e.g. Recommendation ITU-R M.2160-0. Framework and overall objectives of the future development of IMT for 2030 and beyond.
[39] Smart Networks and Services Joint Undertaking (SNS JU) White Paper Towards 6G Architecture: Key Concepts, Challenges, And Building Blocks.

orchestration system ensuring unified cross-domain configuration, monitoring, and adaptation at scale.

3.2.3. Integrated sensing and communication

Future networks are expected to massively integrate sensing functions alongside communications[40]. While network-based sensing is not completely new, upcoming technological developments are expected to enhance these capabilities. These will enable new use cases based on the collection of data from the surrounding environment – that could ultimately contribute to further blend physical and digital realities.

In the case of fixed networks, optical fibres can be used as a sensing device to detect (environmental) parameters such as temperature, vibrations or strain (pressure)[41]. Current use cases include gathering environmental data (for instance, for early detection of earthquakes or tsunamis[42] or monitoring marine vessels[43]) and to improve network resilience – by e.g. monitoring strain or disturbances in (submarine)[44] cables. The combination of AI with fibre-optic based sensing technologies such as Distributed acoustic sensing (DAS) may provide for wide applications in fields such as transportation, energy or security[45] supporting, for example, smart cities.

Another development for VW/Web 4 is the emerging IEEE 802.11bf (Wi-Fi Sensing standard), which aims to enable the use of Wi-Fi signals for motion detection, gesture recognition, and certain biometric-related sensing tasks[46]. Advantages of this technology include that it could work with current Wi-Fi routers, and it reduces the need for special cameras or wearable sensors. The standard allows VW/Web 4 applications to analyse Channel State Information (CSI) fluctuations to derive spatial data, recognize gestures, and enable more natural interactions with the physical world and at lower cost than using wearables. Some examples of use cases for this technology include home security, elders' care (e.g. detection of intruder's movements or sensing if a senior falls and automatically call for help) or continuous wireless heart-rate-monitoring[47].

Industry standard bodies have started working in this sensing field in the context of 5G and 6G. For example, 3GPP is exploring 5G wireless sensing[48] to get information about characteristics of

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[40] Sensing networks refer to systems composed of interconnected sensors that collect, transmit, and sometimes process data about physical or environmental conditions. These solutions are typically implemented through Wireless Sensor Networks (WSNs) or Internet of Things (IoT) framework.
[41] Physical changes along the fibre cause characteristic backscattering of the light signal; by analysing this backscatter with a laser-based system, the network can detect and locate such changes.
[42] See SMART Cables. It is expected that the new submarine cable ring (ring connecting the Portuguese mainland and Azores and Madeira archipelagos) will enter into service in late 2026. This will be a Science Monitoring And Reliable Telecommunications (SMART) subsea cable system (see e.g. https://www.asn.com/press-release/anel-cam/?).
[43] Bob Paap, Vincent Vandeweijer, Jan-Diederik van Wees, Dirk Kraaijpoel, Leveraging Distributed Acoustic Sensing for monitoring vessels using submarine fibre-optic cables.
[44] https://techneconomyblog.com/2025/04/01/submarine-cable-sensing-for-strategic-infrastructure-defense-and-arctic-deployment/.
[45] Shao, L., Zhang, J., Chen, X. *et al.* Artificial intelligence-driven distributed acoustic sensing technology and engineering application. *PhotoniX* 6, 4 (2025). See also https://ieeexplore.ieee.org/document/10547188.
[46] WBA white papers. Wi-Fi Sensing, 2024 Edition.
[47] See https://spectrum.ieee.org/wi-fi-signal-heartbeat-detection.
[48] Technical Specification Group TSG SA; Feasibility Study on Integrated Sensing and Communication (Release 19).

the environment and/or objects within it (e.g. object's shape, size, orientation, speed, location, distances, or movement) by analysing transmissions, reflections, and scattering of wireless sensing signals. Potential use cases include object detection and tracking, environmental monitoring and human motion sensing. These features could be used by industry verticals – e.g. to drones' management, enable smarter homes, or enhance V2X communication, etc.

The ITU[49] also underlines how IMT-2030 (6G) is expected to integrate sensing with communication to offer wide area multi-dimensional sensing capabilities. In practice, future networks could gather spatial information about unconnected, as well as connected, objects and devices and their movements and surroundings.

ETSI[50] has also published a document on the use cases and deployment scenarios for Integrated Sensing and Communications (ISAC)[51] building on previous related work such as the Reconfigurable Intelligent Surfaces (RIS)[52], a new type of network node that can be dynamically configured to improve communication performance, positioning accuracy, and sensing capabilities.

Industry vendors (e.g. Huawei[53] and Ericsson[54]) note the potential of 6G to implement ISAC due to the use of higher frequency bands and increased number of antennas. ISAC could be the basis to develop solutions that exploit data collected by the network sensors or digital twins, as well as to improve network performance. However, this will require further 6G standardization (still at an early stage) and addressing other challenges such as privacy risks (associated with ubiquitous sensing) or, very importantly, deployment costs and return on investment (RoI) considerations.

Likewise, the SNS JU white paper[55] describes how 6G can natively integrate sensing into the (mobile) communication infrastructure – essentially allowing it to perform sensing as part of its normal operation[56].

3.2.4. AI and ECN/S integration

ECN/S are expected to enable and benefit from AI. BEREC already started to examine this matter in the Report on the impact of Artificial Intelligence solutions in the telecommunications sector on

[49] Recommendation ITU-R M.2160-0. Framework and overall objectives of the future development of IMT for 2030 and beyond.
[50] See https://www.etsi.org/technologies/integrated-sensing-and-communications.
[51] ETSI GR ISC 001 V1.1.1 (2025-03) Integrated Sensing and Communications (ISAC); Use Cases and Deployment Scenarios.
[52] ETSI GR RIS 001 (V1.1.1) (04/2023): "Reconfigurable Intelligent Surfaces (RIS); Use Cases, Deployment Scenarios and Requirements".
[53] See https://www.huawei.com/en/huaweitech/future-technologies/integrated-sensing-communication-concept-practice
[54] See https://www.ericsson.com/en/blog/2024/6/integrated-sensing-and-communication.
[55] Smart Networks and Services Joint Undertaking (SNS JU). White Paper Towards 6G Architecture: Key Concepts, Challenges, And Building Blocks.
[56] One possibility is by adopting Channel State Information (CSI), relying on the connectivity between the base station and the user equipment to estimate channel conditions to extract information based on the angle and time difference of arrival. Another possibility is a "radar" sensor approach where the network uses its own radio signals to sense and comprehend the surrounding physical world analysing the reflections and scattering of the wireless signals to obtain information on the environment.

regulation[57], acknowledging the pivotal role that AI is expected to play in future networks. We refer to this targeted report for a more comprehensive view of this matter.

ECN/S providers can benefit from AI and network sensing capabilities to develop e.g. digital twins of their networks. Such digital twins can support network management and operations by, e.g. predicting network congestion and dynamically optimizing bandwidth allocation. They can also assist in network planning or monitor infrastructures to predict potential failures and optimize/streamline maintenance processes.

While AI systems are relevant to any type of network (for instance, ETSI proposes achieving a level 4 - “High Autonomous Networks” to enable F5G configuration, self-healing, and self-optimization[58]), AI is defined as a foundational pillar for future 6G networks. Namely, ITU 6G recommendations[59] build around the use of AI and also the design of 6G systems to support distributed computing and AI applications.

4. Business case for ECN/S providers

Industry technologists have described VW/Web 4 as a compelling frontier of innovation, poised to deliver substantial returns and redefine the way users interact with the Internet. Along the lines of this vision, several consultancy studies predict that VW/Web 4 would unravel substantive business opportunities, with the more optimistic global revenue prospects reaching trillion US $ by 2030[60]. On the other hand, the demand for these innovative use cases, the expected RoI and business cases to monetize these new emerging services are at this stage uncertain or to be developed.

At the same time, realising the full potential of Web 4 and immersive services at scale (i.e. widespread adoption of data-intensive AR/VR/digital twin applications), will require significant investments in networks and digital infrastructures. Particularly, in fibre-based broadband and widespread 5G Standalone (and future 6G), foundational to deliver the required bandwidth and ultra-low latencies. Complementing this, investments in edge computing infrastructures – i.e. the deployment of data centres or edge nodes located close to end-users – are necessary to effectively handle data-intensive, latency-sensitive VW/Web 4 applications[61]. In this context, the

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[57] See https://www.berec.europa.eu/en/document-categories/berec/reports/berec-report-on-the-impact-of-artificial-intelligence-ai-solutions-in-the-telecommunications-sector-on-regulation.

[58]See https://www.etsi.org/newsroom/blogs/entry/etsi-released-the-f5g-advanced-generation-definition-promoting-the-evolution-of-f5g.

[59] Recommendation ITU-R M.2160-0. Framework and overall objectives of the future development of IMT for 2030 and beyond.

[60] In “The Metaverse what’s in it for Telcos?” ADL presents an opportunity range varying from US $ 750 million to $13 trillion by 2030, where this last figure accrues when considering a broad definition of activities. In “Metaverse and money”, City GPS quotes the same figure as the most optimistic value for 2030.

[61] In addition to that, academic research indicates that immersive XR and digital twin applications will benefit from combining 5G/6G and edge cloud for offloading rendering tasks, also acknowledging the need for innovations and investments in future ECN and edge infrastructure. See https://www.researchgate.net/publication/394570585_Shared_Presence_via_XR_Communication_and_Interaction_Within_a_Dynamically_Updated_Digital_Twin_of_a_Smart_Space_Conceptual_Framework_and_Research_Challenges.

European Parliament has emphasized that investing in high-performance connectivity infrastructure should be a priority to harness the full potential of VW[62]. On the 10th of December 2025 the EC has launched the European Partnership for Virtual Worlds, under which it plans to allocate €200 million between 2025 and 2030 to research and innovation activities, to be matched with at least €200 million more funded by the Virtual Worlds Association members[63].

4.1. Challenges

4.1.1. Market evolution uncertainties

Despite the promising potential of VW/Web 4, the future trajectory of these developments is highly uncertain – and, because of this, the business case for substantial infrastructure investments is unclear.

First, the timeline of developments/market growth (and, therefore, of derived revenues) is unknown, since it depends not only on the consumer's uptake of VW/Web 4 services, but also on the progress of multiple players with differing objectives (advances are needed in devices, platforms, applications and services)[64]. Moreover, recent industry trends even suggest that interest (on "metaverse") has currently waned in favour of AI-related services, raising further questions about demand as well as timing and investment focus [65]. Nevertheless, the convergence of AI and immersive environments remains a potentially important area for innovation and could help revive interest in the future

Second, the eventual market structures and business models of VW/Web 4 are non-predictable, affecting the role that operators may play and complicating their investments' planning. This is mainly because the demand (and business case) for connectivity services will be affected by the size of the VW market (which depends on market structure) and, also, because operators may safely invest to provide VW services to different extents depending on the VW market structure. For example, it is difficult to foresee whether the future will bring a unified open ecosystem with broad interoperability and data portability[66], and thus higher demand and broader adoption of VW services or, rather, a landscape of closed systems controlled by a few leading players using proprietary standards and technical solutions that prevent or hinder interoperability between

[62] See Texts adopted - Virtual worlds – opportunities, risks and policy implications for the single market - Wednesday, 17 January 2024.

[63] See https://digital-strategy.ec.europa.eu/en/news/european-commission-launches-european-partnership-virtual-worlds.

[64] Regarding this "chicken and egg problem", a 2022 Citi report by Dani Grant and Nick Grossman explains that in the history of new technology development, infrastructure and app development do not appear in a sequential process with infrastructure being built first, followed by the apps. Instead, infrastructure and applications evolve in an iterative, cyclical way. The first few apps are often built on sub-optimal infrastructure. Then the arrival of a wildly successful breakout app leads to further investment in the underlying technologies, drawing fresh development efforts into easier-to-build and more-usable apps, and the virtuous cycle continues. That is, enhanced networks and digital infrastructures are a driver for advanced digital services and vice-versa.

[65] See, for example, The 6G Manifesto. William Webb. 2024.

[66] This is allowing users and businesses to easily/seamlessly "roam" or transfer their assets across different applications.

platforms resulting in a smaller adoption of VW services, but yielding higher revenues for those providing them.

4.1.2. The complexity of the ecosystem of the VW/Web 4

As BEREC has noted in previous reports[67], the digital ecosystem is currently developing under "coopetition" dynamics where different players both compete and cooperate under different roles. Such complex relationships might hinder investment decisions if agreements are not reached or in case of uncertainty on the economic feasibility and business models to capture RoI across the value chain.

The development of VW/Web 4 services relies on a complex ecosystem composed of many (interrelated) building blocks – connectivity and digital infrastructures, platforms, devices, operating systems, content, AI systems, etc.

BEREC notes that major content and application providers (CAPs)/platforms are already firmly established in the wider digital services landscape. These entities often function as complex conglomerate ecosystems that possess not only specialized expertise and capabilities, but also strategic assets such as vast user bases, access to capital, extensive digital infrastructures (e.g., data centres, edge nodes, CDN or connectivity) and data resources[68]. Such competitive advantages underpin the delivery of numerous digital services and present a credible risk that the dominance of today's leading platforms could carry over into virtual environments and the emerging Web 4 landscape.

In summary, an ecosystem composed of vertically integrated firms operating across many layers – and in adjacent sectors as cloud services or devices – combined with strong network effects and economies of scale, heightens the risk of market concentration and related competition concerns. This may impede or disincentivise new or smaller entrants from offering innovative and/or differentiated services[69]. This risk would be further amplified if closed, proprietary systems emerge, locking in consumers and content/application developers and therefore limiting their capacity to seek alternative services or engage with multiple platforms. Some of these competition concerns are already being targeted by digital legislation such as the Digital Markets Act (DMA).

4.2. Business opportunities

ECN/S providers must weigh the financial costs of long-term irreversible infrastructure investments against the expected revenues from connectivity and interlinked VW initiatives (deployed by them or other players). Sufficient investment returns are necessary to justify the required capital expenditures (capex) and ensure ongoing, sustainable network evolution.

[67] See BEREC Report on the entry of large content and application providers into the markets for electronic communications networks and services; BEREC Report on the Internet Ecosystem or BEREC Report on Cloud and Edge Computing Services.
[68] When leveraged effectively, these assets enable the extraction of timely and valuable insights into consumer and business behaviour.
[69] Such practices might also marginalise ECN/S operators, especially the smaller ones, constraining their market entry and innovation opportunities.

Today a perception, shared by a lot of actors, in the ECN/S sector is that demand for the most advanced networks and communication services is limited[70]. However, the expectation of infrastructure investments' profitability may change if VW/Web 4 services increase end users' willingness to pay for higher-quality connectivity or edge computing capabilities. In addition, VW/Web 4 might generate new revenue sources – including agreements where application and service providers contribute, directly or indirectly, to the required enhanced connectivity and computing infrastructures.

The next subsections outline several possible business opportunities for ECN/S providers in the scope of VW/Web 4, which may help raise revenues or achieve efficiency gains, thereby supporting sustainable investments in network and connectivity developments. The extent to which those new sources of revenues will outweigh costs will be key for the eventual success of VW/Web 4.

4.2.1. Selling advanced connectivity

Providing connectivity services, has been, up to date, the core business of ECN/S operators. The traditional operator's business model has long centred on the sales of ECS subscriptions to end-users (often bundled with non-telecom services), looking to extend its customer base and reach broad coverage of ECS. In mature markets with very high service penetration (like European ones), further growth in this model depends on persuading customers to pay more for better quality connectivity. Yet, willingness to pay a premium relies on the availability of digital services that truly require enhanced ECS/N performance. These developments are often uncertain and largely not in the control of telecom operators – VW/Web 4 being an example of this. In fact, some operators contend that the traditional subscription model has stagnated and is now insufficient to support the network investments required for the VW/Web 4 ecosystem[71].

However, alternative value propositions could yield new connectivity revenue sources, as ECN/S providers may be able to charge for special connectivity services or premium service-level agreements (SLAs) – either charging the end-user or the VW/Web 4 services provider. For example, a user who wants to experience a fully interactive/immersive experience in e-sports, may pay a surcharge for the required high-performance connectivity. Or, if a user "test drives" a new car in a VW scenario, the car manufacturer or dealer might bear the cost of a suitable connectivity to enable that experience.

Telco's gaming offers in Europe[72]

[70] See, for example, https://broadbandbreakfast.com/the-5g-promise-falls-short-of-reality-examining-economic-impact-claims-2/ or https://www.fierce-network.com/broadband/remember-5g-hype-heres-whats-actually-happening-now
[71] See for example, the 2023 "Telecommunication Networks and Metaverse. A new era for the Internet". Digital Public Policy, Regulations and Competition Position paper of Telefonica.
[72] See **Chapter 2** and **Annex II** for a general perspective of this use case.

In Europe, major operators such as Deutsche Telekom (DT), Vodafone,[73] Telefónica,[74] and Orange[75] have launched gaming bundles and partnerships. For instance, DT rolled out a "5G+ Gaming" offer (giving access to 100 top games such as Fortnite, PUBG, 9 years of Shadow)[76]. To activate the offer, the end-user has to switch to DT's 5G SA network (also available to all customers without the 5G+ gaming option).

More broadly, the expected development of VW/Web 4 will generate a "long-tail" connectivity market[77], where communications need to be tailored to specific use cases – often pivoting on particular industries or businesses sectors rather than general consumers[78] (see also **Chapter 2** and **Annex II**). With tools like 5G network slicing, operators can deliver sector-specific high-quality connectivity (e.g., dedicated network slices for healthcare or industrial digital twins). This kind of service tiering can generate additional revenue streams and make investments in advanced connectivity networks more profitable. Certain sectors (smart manufacturing, the tactile internet, etc.) demand a mix of diverse performance capabilities – (ultra-)low latency, very high reliability, support for massive device density – which 5G SA and (future) advanced ECN infrastructure (e.g. 6G) are designed to deliver. ECN/S providers can tailor their commercial offerings accordingly to meet these requirements.

Orange's network slice trials[79]

Orange, has conducted trials (in its 5G Lab) with Huawei to test end-to-end network slicing in a cloud gaming environment, showing dynamic management of network resources to guarantee premium, uninterrupted gaming performance. In practice, this test split network traffic into standard and priority slices, managing traffic based on the game's requirements – a key approach for latency-sensitive applications like VR streaming and cloud gaming. A follow-up test (July 2024), involved implementing on-demand slice configuration for the cloud gaming service, demonstrating the ability for users to request and obtain a certain QoS dynamically, in real time.

Building on this functionality, operators may in the future offer standardized, easy-to-use APIs for services that leverage the (5G) network capabilities and to deliver first-rate experiences for gaming, holographic communications or VR sessions.

All in all, there is an opportunity for operators to generate new revenues from "customized" connectivity, by charging premium customers for service levels linked to advanced services or

[73] See https://www.vodafone.co.uk/newscentre/news/hundreds-of-games-from-tenner-a-month-with-xbox-game-pass.
[74] See https://opengateway.telefonica.com/en/resources/documents/case-study/case-study-blacknut?utm.
[75] https://5glab.orange.com/en/realisations/how-will-slicing-help-to-make-cloud-gaming-seamless/.
[76] Developed in partnership with ALSO (leading provider of the ICT industry) and Ludium lab (tech company specialised in cloud solutions).See https://www.telekom.com/en/media/media-information/archive/next-level-gameplay-new-5g-gaming-offer-now-available-1081828 and also https://www.game.de/wp-content/uploads/2024/08/Annual-Report-of-the-German-Games-Industry-2024.pdf. More recent offer can be found here: https://www.telekom.com/en/media/media-information/archive/5g-gaming-with-nvidia-1095300.
[77] This is, one with many layers and a large number of diverse services, which may cater for the needs of specific groups - as opposed to general needs.
[78] See "Making 6G profitable. How will business and technology factors combine for a successful 5G to 6G transition", (2024).
[79] See https://5glab.orange.com/en/realisations/how-will-slicing-help-to-make-cloud-gaming-seamless/.

explore various innovative revenue- and risk sharing schemes in partnerships, as discussed in this document.

Network as a Service (NaaS)

The NaaS paradigm has been proposed as a possible enabler to support the development of advanced services including those in the VW/Web 4 context for example, by means of the identification of the closest cloud edge zone for those services that require extreme low latency[80]. This would imply delivering connectivity and network capabilities by means of programmable platforms, so that platforms can directly integrate specific network quality parameters and functions into (the design of) their applications. In practice, this model would allow developers to treat certain network functions as programmable on-demand resources via APIs[81]. If those APIs are standardized across operators, it would facilitate widespread NaaS adoption. This solution could foster innovation through a "trial-and-error" approach to service creation – where successful experiments in leveraging networking programmability are rewarded.

However, it is unclear how commercial arrangements (and payments) would be established in the NaaS context, e.g. whether end-users, service providers or developers pay network operators to manage the network qualities their applications need. Yet, it should be noted that not all agents will be equally equipped to negotiate technical interfaces and pricing on a case-by-case basis with each operator, which could introduce significant transaction costs. This could be a problem for small ISP or VW providers, which may struggle to reap benefits of NaaS[82].

4.2.2. Edge computing

BEREC's 2024 Report on Cloud and Edge Computing noted that ECN/S operators may possess an advantage in the edge computing value chain due to their existing, widespread infrastructure and capillarity, which would enable them to offer services closer to end-users. This proximity is crucial for reducing latency and enhancing quality of service, potentially allowing operators to play a key role in the development and widespread adoption of edge computing for certain services, including many VW/Web 4 applications.

Yet, despite this inherent advantage – and the strong synergies between edge computing and 5G SA (and distributed local fixed nodes) for high bandwidth, low-latency applications – BEREC observed (in the same report) that the outlook of operators on edge computing investment is relatively pessimistic, pointing to weak incentives to invest in extensive edge infrastructure in the short to medium term. This reluctance reflects several significant hurdles to developing edge

[80] See https://camaraproject.org/simple-edge-discovery/

[81] The concept of NaaS extends beyond the area of VW. Currently the APIs provided by operators relate to device location, identity authentication, messaging, fraud detection, etc which are somewhat unrelated to VW. Yet, a few APIs have been developed that may support VW. For example, quality on demand APIs that make possible to develop services that require advanced network capabilities like ensuring a stable connection or increased latency, which can be used in XR scenarios like immersive learning, immersive entertainment and e-health services.
For example, the Portuguese operator MEO stated that APIs play an essential role in digital transformation by offering fast and efficient solutions for creating services in areas such as security, robotics and health (https://en.meo.pt/business/news-real-stories/latest-news/2024/novembro/5g-api-sprint-transformaca-digital-organizacoes).

[82] And may threaten end-users' abilities (whether service developers or consumers) to freely access and distribute information or to run the applications and services of their choice.

computing infrastructure. These include the complexity of deploying and maintaining a large number of distributed edge nodes, various uncertainties stemming from the complex application of several norms, and the difficulty in predicting future market needs and demand for edge services. Moreover, edge computing is considered as being complementary to cloud computing, and, as technology evolves, cloud providers are providing services that may substitute some of the functionalities associated with edge computing, thus hindering its business case.

Crucially, BEREC observed that very few commercially viable use cases currently require the ultra-low latency capabilities of edge computing. This lack of demand hampered the business case for private investment and delays the widespread deployments necessary to meet EU targets (e.g., of the total goal of 10,000 edge nodes by 2030, only 2,257 were deployed as of 2024[83]).

Furthermore, on top of the uncertainties regarding demand and the monetization of new edge services, cloud services - particularly those owned by hyper-scalers- may substitute for some edge computing functions. This could be, for example, in the case of regional clouds deployment bringing them closer the users that, ultimately, may diminish the demand for some edge computing functionalities. This adds on to the hesitant investment outlook of ECN/S operators, which remain cautious about heavy investment in edge computing.

4.2.3. Provision of VW/Web 4 services and related goods and services

Operators can engage in the provision of VW/Web 4 services and related activities through two primary models by: (i) investing directly in building and offering such services, or (ii) establishing partnerships with platform providers and device manufacturers. In this model, operators may act as value-added resellers (for example, by bundling advanced connectivity with immersive digital services or devices) or, rather, assume a more active role by helping in the delivery and orchestration of specific platform functions. Either approach marks a strategic shift for operators – from being pure infrastructure providers toward becoming digital experiences' enablers. Yet, this requires a careful balancing between these new roles and operators' core network competencies.[84]

A few ECN/S operators have engaged directly in the provision of VW/Web 4 services (see examples above and below); however, a major challenge is that operators generally lack the expertise and, mainly, would be competing with better positioned companies, such as established digital platforms, which may capture much of the value in the VW/Web 4.

[83] DESI 2025. DESI dashboard for the Digital Decade (2023 onwards) - Digital Decade DESI visualisation tool

[84] Accenture (2022). Meet me in the Metaverse: The continuum of technology and experience reshaping the Communications industry.

Ifland (2021-2025)[85]

Ifland is one example, backed primarily by SK Telecom (South Korea) since its launch in July 2021. It focused on providing 'social VR' services – like avatar creations, virtual spaces for social gatherings, community activities, global events (real-time concerts, K-pop meet and greets) and integrated communication tools. By late 2022, it was available across 50 countries (in several of those through partnerships with local operators) and reported over 12.8 million total users[86]. SK Telecom explained that there was "great attention" towards Ifland from businesses, with more than 1,500 requests for partnerships[87]. Yet, on March 31, 2025, SK Telecom terminated the Ifland platform as a result of a strategic shift in its focus, to AI technologies[88].

The Luxembourg Metaverse[89]

In another case, in July 2022, Orange announced its virtual Orange Digital Center (ODC) in Luxembourg, which focuses specifically on metaverse-related activities. The virtual ODC aims to support startups, promote digital literacy, and raise awareness about both the opportunities and risks of virtual environments. It is open to all and dedicated to digital innovation and skills development. It hosts conferences on technological innovation, offers educational content about the metaverse, and provides guidance on best practices for navigating virtual spaces. It aims to explain what the metaverse is to raise awareness about the dangers and possibilities that this environment represents.

In the future, operators could explore partnerships with established players to deliver immersive experiences and related services. In such collaborations, the role of operators will become increasingly important as their assets and expertise grow more relevant and central – particularly as immersive services will demand more customized(advanced) connectivity solutions, extensive network reach (capillarity), and robust edge computing capabilities, including the potential use of distributed intelligence at the network edge (e.g. mini-clusters) to mitigate latency and processing bottlenecks.

ECN/S operators also maintain strong commercial relationships with their customers, supported by established billing systems (clear payment processes) and customer support processes (e.g. well-defined procedures for handling customer complaints). Some reports suggest that a key asset of operators is their strong brands and reputation for being trustworthy parties, that guarantee privacy of identity, data and activities and transactions – these advantages can position them in VW/Web 4 in areas related to consumer data management, securing of transactions, ensuring the verification of identities and cybersecurity and as reliable business partners to distribute immersive services and XR devices – for instance, by bundling VR/AR

[85] Similarly in 2022, Japan's NTT DoCoMo developed a new metaverse technology that can make characters in a 3D online world mirror the movements of their users. They include facial expressions – when users blink or smile, for instance, their avatars do the same in real time. The technology also allows users to synch their body movements with their avatars – punching and kicking are mimicked. This feature can help improve customer services and it can also liven up online events.
[86] See https://www.communicationstoday.co.in/sk-telecom-launches-its-metaverse-platform-ifland-in-49-countries/.
[87] See https://www.huawei.com/en/huaweitech/publication/202207/telco-initiatives-metaverse#text3.
[88] https://www.telecoms.com/metaverse/sk-telecom-pulls-the-plug-on-ifland.
[89] See Metaverse | Orange Luxembourg.

hardware with connectivity offerings[90]. By bundling goods and services, ECN/S operators could even serve as a one-stop shop for VW services and devices, providing both the network connectivity and services and the related gadgets.

Vodafone and Nreal deal

Vodafone has established a collaboration with Nreal to bring Nreal's 'Light AR' glasses to the European market. With this partnership European consumers and businesses may access AR and MR experiences powered by Vodafone's high-speed 5G network. The Nreal Light glasses were launched first by Vodafone in 2021 in Germany and Spain. They could be purchased as a bundle with a compatible 5G smartphone or separately[91]. Moreover, Vodafone developed an exclusive AR app (Vodafone 5G Reality AR) to make it available to Nreal Light users, enabling features like a customizable virtual dashboard, watching videos, web browsing, and arranging multiple virtual screens.

Telefonica and Meta agreement[92]

In March 2022, Telefónica and Meta partnered to create a Metaverse Innovation Hub in Madrid, aimed at accelerating the technological development of Europe. It was meant to provide startups and developers with access to cutting-edge infrastructure to test and develop metaverse applications, by granting access to a 5G laboratory where they can use end-to-end testbeds on Meta and Telefónica's network infrastructure and equipment. News about this venture stopped by early 2023. Wayra, Telefónica's open innovation arm, launched (March 2022) a call to source startups to contribute to the development of the metaverse with a focus in areas such as connectivity (5G, edge computing), devices (XR, AR/VR hardware), immersive environments, identity tools (avatars, digital ID) and non-fungible tokens (NFTs) and marketplaces.

Deutsche Telekom (DT), Niantic and MobiledgeX partnership[93]

The partnership between DT, Niantic, and MobiledgeX was announced in October 2018. It aimed to integrate Niantic's Platform—which powered games like *Pokémon GO*—with MobiledgeX edge servers and Deutsche Telekom's 5G network in order to deliver low-latency, multiplayer AR experiences. MobiledgeX was acquired by Google Cloud in 2022 and there have been no updates confirming the continuation of this partnership. Yet, DT remains active in AR. For example, in 2024, it partnered with Accedo (interactive video solutions) and Snapchat (AR lenses and fan engagement) to enhance the football fan experience during UEFA's Euro 2024 by procuring XR and AR technologies that allowed for immersive content and interactive AR filters as well as real-time fan engagement[94].

[90] See Arthur D Little, 2022, "The Metaverse: What's in it for telcos?"
[91] For example, in Spain, customers could obtain the glasses through monthly payment plans, with or without an Oppo Find X3 Pro 5G device.
[92] See Telefónica seeks startups worldwide with metaverse use cases.
[93] See https://www.telekom.com/en/media/media-information/archive/deutsche-telekom-niantic-and-mobiledgex-partnership-545528
[94] See Telekom ermöglicht gemeinsam mit Accedo und Snapchat innovative XR- und AR-Lösungen | Deutsche Telekom.

Overall, at this early stage of the VW/Web 4 development, operators are collaborating with different partners to examine technological development and opportunities. Time is needed to assess the outcomes of these initiatives and how ECN/S operators could benefit.

4.2.4. Developing new ECN/S services: sensing-networks

As noted in **Chapter 3**, integrated sensing networks play a key role in the development of VW/Web 4, particularly for VR and AR[95]. VR/AR headsets with built-in sensors combined with sensing networks, can track user movements with high precision and minimal latency, allowing real-time data exchange to synchronize user actions with (their) virtual representations.

As essential infrastructure providers, ECN/S operators are well positioned to seize business opportunities in the sensing networks. First, they provide the network infrastructure (5G, and in the future, 6G) needed to carry the real-time transmission of the vast streams of data generated by XR sensors and devices. Second, they can leverage their networks and data management capabilities to integrate diverse types of sensor data (depth cameras, LIDAR, whole-body trackers, physiological sensors, etc.), thereby enriching XR user experiences. Third, they can ensure secure data management and delivery, crucial when private and sensitive data is collected by XR applications. Finally, they can lead technological innovation and standardization processes (for example, through testbeds like Open RAN) and therefore contribute to shaping standards for next-generation networks (e.g. for 6G) that promote interoperability and security.

Clearly sensing networks can be used in multiple domains beyond XR and there are several of such sensor-network initiatives by European operators. For example, DT[96] has rolled out sensor-based systems to monitor parking availability and traffic flows in several German cities, as well as to track pollution levels and urban microclimates. Orange has deployed sensor networks in factories to monitor equipment performance, anticipate failures and improve quality maintenance[97]. Building these capabilities is also essential for advancing XR applications.

4.2.5. Enhanced efficiencies resulting from VW/Web 4 solutions used by operators

Lastly, operators can adopt VW/Web 4 solutions (e.g. XR) internally to improve delivery of ECN/S and/or to reduce costs. First, as in many other sectors, VW/Web 4 solutions/tools can be used by operators in areas like human resources (e.g. providing VR training programs or conducting remote interviews in virtual environments), or marketing (showcasing services or devices via AR[98]). They may also enable virtual rooms to improve overall company collaboration, knowledge transfer and remote support, among other operational activities.

[95] They capture data from the physical world (geometry, texture, spatial relationships) using devices like depth cameras and light detection and ranging technologies (LIDAR) and this allows reconstructing and blending real spaces into virtual environments.
[96] See IoT Use Cases & References | IoT Telekom for several use cases of sensing networks pursued by Deustche Telekom.
[97] See Which are the use cases for IoT in Industry | IoT Journey for more examples of Orange's experience with IoT for industrial applications.
[98] Vodafone Turkey is preparing to open its first store in the metaverse. The Vodafone Metaverse Store will open in Decentraland and offer customers the convenience of accessing Vodafone products and services in the virtual

Second, VW/Web 4 technologies can be applied to ECN/S operators' own applications, network planning and design, operation, and maintenance. For example, operators can use digital twins of their (critical) network infrastructures and assets to manage them more efficiently – allowing real-time monitoring of their use, better planning of maintenance and simulation of updates or extensions. This can also allow optimized energy usage, an issue of relevance for operators.

In fact, several European operators are already experimenting or deploying large-scale digital twins of their networks.

Vodafone's Digital Twin Strategy[99]

Vodafone has developed a 3D digital twin of its UK passive infrastructure (mast) network, enabling its engineers to remotely visualize and strategize network improvements or expansions. The digital twin maps 40 million environmental features (using GIS software) to identify signal obstructions and optimize site placement, and it provides access to a 360º virtual view of over 500,000 network components. With this digital twin, engineers can remotely inspect network infrastructure before dispatching field teams and can plan expansions or upgrades based on real-time environmental and performance data[100]. Vodafone is also testing this digital twin approach for its networks in Germany and Turkey.

Ericsson Digital Twins for 5G Networks in NVIDIA Omniverse

Ericsson is developing city-scale digital twins to accurately simulate the interplay between 5G cells and the surrounding environment, to maximize performance and coverage[101]. As Ericsson explains, without a digital-twin approach, the interaction between radio transmitters, the environment, and moving users/devices can only be understood with less detail – meaning many aspects would have to be field-tested only after the networks were built.

5. Regulatory challenges

While VW/Web 4 extend well beyond the traditional scope of electronic communications regulation, the technological and market developments described in the previous chapters rely on robust, secure and future-ready connectivity and services. In this context, BEREC and NRAs are monitoring the evolution of VW/Web 4, assessing how existing regulatory tools and principles

universe. This will be the first store opened in the metaverse among Vodafone Group countries. Vodafone Metaverse Store will have special areas for hosting campaigns of Vodafone's brands such as Red and FreeZone, as well as areas for environmental, social, and governance initiatives. The company's personal digital assistant Tobi will welcome visitors to the store.

[99] See Vodafone's mobile network has a digital twin and 3D digital twin helps Vodafone in network planning - GIS user technology news

[100] The digital twin provides Vodafone engineers with a real-time, interactive platform to visualize signal propagation, model environmental impacts ("clutter"), and plan or optimize the expansion and improvement of the network. This allows for smarter, data-driven decisions about where to deploy new infrastructure (including Massive MIMO) or upgrade existing assets to maximize connection quality and coverage.

[101] See Ericsson Builds Digital Twins for 5G Networks in NVIDIA Omniverse | NVIDIA Blog and 5G simulation models with NVIDIA oniverse platform - Ericsson.

– including open internet rules, the European Electronic Communications Code (EECC) and the spectrum framework – remain fit for purpose.

Given the early stage of this ecosystem and the rapid pace of technological change, regulators should monitor these advancements, understanding how VW/Web 4 services and business models evolve, and how they interact with ECN/S. This is a prerequisite for considering any potential adaptations of the regulatory framework, so as to support innovation and investment while safeguarding core principles such as non-discrimination and end-user protection.

5.1. Fostering investment in digital infrastructures

As described in Chapters 2, 3 and 4, some VW/Web 4 scenarios are expected to increase requirements for very high-capacity, low-latency networks and for complementary infrastructures such as edge and cloud computing[102]. Many VW/Web 4 applications are likely to run over existing VHCN, but network evolution will still require substantial investments in fixed and mobile networks and in distributed computing capabilities. This raises the challenge of incentivizing sufficient investment in digital infrastructure (helping) to overcome the possible difficulties for such deployments.

In this context, regulatory predictability is an important enabler. Clear, transparent and consistent application of the existing framework – including the EECC provisions on promoting efficient investment and innovation, and on allowing co-investment and infrastructure sharing under appropriate safeguards[103] – can facilitate long-term investment decisions[104], particularly where demand and revenue prospects for VW/Web 4-related services remain uncertain[105].

When it comes in particular to the competitive roll-out of ECN/S, BEREC notes that *ex-ante* regulation enforcement by NRAs has proven to be a suitable and flexible instrument and will continue to be essential in the coming years to address bottlenecks. Public policy instruments and co-operation models can also contribute to closing connectivity gaps and facilitating upgrades. EU and national funding programmes and State aid schemes can support deployments in high-cost or low-density areas, while voluntary partnerships between operators and other actors (for instance, cloud providers hosting edge nodes within operators' networks) can help share costs and risks. When designing such incentives and frameworks, policy-makers and regulators

[102] See e.g. [BEREC high-level position on artificial intelligence and virtual worlds]

[103] European Electronic Communications Code (EECC) – Directive (EU) 2018/1972, Article 3(2)(d). This provision directs regulators to "*promote efficient investment and innovation in new and enhanced infrastructures*", including by permitting various cooperative arrangements between investors and access seekers, while ensuring competition and non-discrimination. In practice, NRAs can encourage joint investments (co-investment deals, network sharing, etc.) under the safeguards outlined in the EECC.

[104] See e.g. https://www.iicom.org/wp-content/uploads/IM-April-2020-Vol-48-Issue-1_Duncan-and-Weekes.pdf.

[105] As observed in previous chapter(s), ECN/S operators face high upfront costs to upgrade infrastructure for immersive services, while the revenue models for many new VW applications remain unclear and unproven. For example, data traffic is forecast to increase dramatically (possibly 20-fold this decade), which will require continuous upgrades; yet if user uptake of advanced VR/AR services is slower than expected, returns on these investments are uncertain.

should also consider broader objectives such as network security and resilience, affordability for end-users and effective competition[106].

5.2. Openness and interoperability

At network level, the main instrument to safeguard openness in VW/Web 4 scenarios is the EU Open Internet Regulation (OIR)[107]. BEREC has consistently underlined that compliance with the OIR principles – in particular non-discriminatory traffic management – remains essential as new, more demanding services emerge. As a principle-based and technology-neutral instrument, the OIR is designed to apply also to evolving connectivity solutions and business models, including those linked to VW/Web 4.

VW/Web 4 connectivity may in practice rely on different types of deployments. Some services will run over IAS and be fully subject to the OIR. Others, for example those requiring certain QoS, might fall under specialised services within the meaning of Article 3(5) OIR, or may rely on private networks which fall outside the scope of the OIR[108,109]. In this context, the existing technology-neutral framework requires that any differentiation mechanisms (for instance, those enabled by network slicing or edge computing) do not undermine the general open-internet principles or the quality of IAS. Where needed, BEREC could provide further guidance on the application of the OIR to new connectivity solutions[110].

Beyond connectivity, openness at the level of platforms and ecosystems – in particular interoperability and data portability – will also influence how VW/Web 4 develop. Today, most VW remain siloed and based on proprietary solutions[111], which can limit users' ability to move their identity, data and digital assets across services and may strengthen the position of large platforms. The EC's Communication on Web 4.0 and virtual worlds[112] and broader digital legislation – including the DMA[113], the GDPR and the Data Act – already address several of these

[106] The European Parliament, for its part, has acknowledged that significant investments will be needed to adapt and upgrade networks for Web 4.0; it has called for finding ways to ensure powerful 6G networks in the future that can enable advanced VW applications. This underscores that fostering infrastructure investment is not solely a telecom sector issue but a broader strategic goal for Europe's digital future.
[107] Article 3(1) OIR grants end users the right to access and distribute information and content, and to use and provide applications and services of their choice via their internet access service (IAS).
[108] The high bandwidth and real-time requirements (very low latency) of certain immersive services, for instance, a VR streaming service or holographic call, might strain networks to the point of impacting other services.
[109] See also Chapter 2 and Annex II (Immersive entertainment (gaming and virtual events)).
[110] E.g. BEREC Guidelines on the Implementation of the Open Internet Regulation BoR (22) 81.
[111] This is despite of the growing efforts to increase interoperability, as shown in the recent ETSI Report: Augmented Reality Framework (ARF); Virtual World Standards Landscape Report ETSI GR ARF 010 V1.1.1 (2025-05).
[112] European Commission (2023), "Web 4.0 and Virtual Worlds" Communication – The Commission's July 2023 strategy document (COM(2023) 442 final) emphasises the need for openness. It notes that open standards will be "*key to ensuring that the future Web 4.0 ecosystem will not be dominated by a select few*" and that large players could otherwise set de facto standards and create entry barriers. The Commission, together with stakeholders, pledges to support common interoperability standards and open-source communities in order to counteract proprietary systems. (See Section 3.2 of the Communication for the discussion on standards and openness).
[113] NRAs, through BEREC, are actively contributing to the DMA High-Level Group which advises the European Commission on DMA implementation. BEREC's involvement helps ensure that issues of interoperability, fair access and contestability – also crucial for virtual world platforms – are considered in the enforcement of the DMA. Notably, BEREC's High-Level Position on AI & VW in 2024 highlighted competition dynamics and internet openness as key areas of concern, reinforcing the importance of the DMA and other tools in keeping Web 4.0 markets open.

issues at horizontal level. **Annex I** provides a more detailed overview of these instruments and of ongoing standardisation initiatives on interoperability.

At the current regulatory framework, BEREC and NRAs focus primarily on safeguarding an open and non-discriminatory internet, while monitoring how VW/Web 4 markets, standards and data-governance frameworks evolve. Within their remit, they may contribute to EU-level discussions on openness and interoperability and assess, in light of market experience, whether additional clarification is needed regarding the application of existing rules to VW/Web 4-related connectivity and services.

5.3. Digital divide and inclusion

The development of VW/Web 4 services may, over time, raise questions about digital inclusion. If immersive applications become relevant for work, education, public services or social participation, gaps in access to high-quality connectivity and digital infrastructures could translate into wider social and economic disparities. To ensure that potential benefits are broadly shared, the availability of reliable, high-capacity connectivity remains a key precondition[114].

In this regard, the main challenge from an ECN/S perspective is the availability and quality of VHCNs, including gigabit broadband and advanced mobile networks, across all regions. EU-level connectivity targets for 2030[115], such as gigabit coverage and 5G in populated areas, provide a reference framework for closing remaining coverage gaps[116]. Within their remit, NRAs and other competent authorities can contribute by applying the existing regulatory toolkit – for example, promoting efficient investment and competition, setting appropriate coverage conditions in spectrum awards, and proposing measures to promote affordability where relevant – in a technologically neutral manner, taking into account, where possible, specific applications such as VW/Web 4.

Digital inclusion in VW/Web 4 will also depend on other factors such as device affordability (for instance, access to suitable XR headsets), digital skills and accessibility of services, which are primarily addressed through broader public policies. These aspects are not specific to the electronic communications sector (or even VW/Web 4) but may become more salient if immersive services gain in importance. **Annex I** and other BEREC work on connectivity and end-user rights provide additional context on how general digital-policy instruments and the electronic communications framework can complement each other in supporting inclusive participation in the digital environment.

5.4. Spectrum

Wireless connectivity – particularly advanced mobile (5G and, in the longer term, 6G) and Wi-Fi – will be an important enabler for many VW/Web 4 use cases, from untethered XR devices to

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[114] See Conference - web 4.0 governance and virtual worlds (2025) | Shaping Europe's digital future and An immersive technologies policy primer | OECD. See also Annex II (e.g. Immersive remote collaboration & telemedicine).

[115] The EC has started the process to review these targets in 2026 by means of a call for evidence

[116] EU Connectivity Targets (2025/2030) – The EU's Digital Decade goals call for all European households to have gigabit connectivity and 5G coverage to reach everyone by 2030. These targets were endorsed in the 2022 Declaration on Digital Rights and Principles, highlighting universal connectivity as a priority. Achieving them is seen as a prerequisite for inclusive Web 4.0: without near-ubiquitous high-speed networks, large segments of society could be excluded from advanced digital services.

dense deployments of sensors and IoT systems (see Chapter 2 and **Annex II** for examples). As described in Chapter 3 and **Annex IV**, these technologies rely on (mobile ECNs and) appropriate spectrum resources to deliver high data rates and low latency. From a regulatory perspective, VW/Web 4 do not change the core objectives of spectrum policy but may reinforce the need for timely availability of suitable bands and for their efficient use.

In the short to medium term, many VW/Web 4 services are expected to use existing harmonised spectrum bands for 5G and Wi-Fi[117]. NRAs and other competent authorities will continue to design award procedures and licence conditions in a technology- and service-neutral manner, taking into account (EU and international regulations and) national circumstances, while supporting both wide-area coverage and additional capacity in hotspots, avoiding harmful interference and ensuring effective cross-border coordination[118].

Some VW/Web 4-related applications, in particular industrial digital twins or other enterprise use cases, may be deployed over local or private networks. Some countries have already introduced local 5G licensing frameworks that allow verticals to deploy their own networks in limited geographic areas[119]. This raises questions on how to design such regimes so that spectrum is used efficiently, competition is not unduly distorted, and private networks can coexist and interoperate with public mobile networks[120]. Experience from these initiatives can inform future spectrum policy choices.

As new generations of mobile technology emerge, including 6G, discussions at European and international level (e.g. within CEPT and ITU) will consider additional bands, potentially at higher frequencies[121]. For NRAs (and competent authorities in some Member States), an important task will be to follow these developments, assess demand and technical conditions, and contribute to a spectrum framework that remains flexible and innovation-friendly, while continuing to serve a broad range of wireless services – mobile (5G-SA, 6G), Wi-Fi, satellite and IoT – beyond VW/Web 4.

5.5. Competition

VW/Web 4 ecosystems are characterised by strong network effects and by the presence of large platform players. There is a risk that a limited number of platforms or providers of foundational technologies (such as operating systems, app stores or VR/AR hardware) could leverage their position to lock in users and business partners or hinder interoperability.

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[117] Wi-Fi 7/8 (using the 6 GHz band) and other unlicensed technologies will play a role for e.g. in indoor or campus settings for AR/VR offloading.
[118] See Smith Institute, “Artificial intelligence for spectrum management”, February 2025, page 34.
[119] Local 5G Spectrum for Industry – Several regulators have opened specific bands for private 5G networks. For example: Germany set aside 100 MHz in the 3.7–3.8 GHz band for local industrial use, and the UK allows localized licensing in the 3.8–4.2 GHz band. These dedicated allocations enable factories, logistics hubs, etc. to run their own high-reliability networks (often to support XR and IoT use cases) without depending on public mobile operators.
[120] Regulators are balancing this innovation with safeguards to prevent interference and to integrate these private networks into the wider communications environment.
[121] And(or) adapted conditions for the use of spectrum resources, including more dynamic and optimised use across time, services, and locations.

As such, many competition questions linked to VW/Web 4 – for example, gatekeeper behaviour[122] by large platforms or device vendors, self-preferencing and lack of interoperability – are addressed at horizontal level by EU competition law and fall primarily within the remit of competition authorities and the enforcement of the DMA and other recent EU Acts (as the Digital Services Act, DSA). BEREC contributes to the implementation of some of these regulations, for instance through its participation in the DMA High-Level Group, by providing expertise on connectivity markets and interoperability, among others. More detailed discussion of these horizontal instruments and of broader competition challenges in VW/Web 4 is provided in **Annex I**.

From an ECN/S perspective, the main question is how VW/Web 4-related developments may interact with competition in connectivity and related services. Traditional electronic communications tools – including market analyses, significant-market-power (SMP) remedies and wholesale access obligations – remain the primary instruments to address risks of foreclosure or discrimination in ECN/S markets. In addition, enforcement of the open-internet rules ensures that internet access providers do not favour their own or partners' immersive services over competing applications in terms of treatment of traffic (e.g. quality), thereby safeguarding end-user choice.

Moreover, lessons learned from the successful implementation and enforcement of relevant *ex ante* regulation for ECN/S markets could be used as a blueprint for elements of the EU's Digital Rulebook going forward, adapted to the specificities of other digital services.

In this early phase, a task for regulators is to monitor developments at the interface between connectivity providers, platforms and device manufacturers – including exclusive partnerships, bundling practices or differentiated quality offers – and to cooperate with competition authorities and other relevant bodies where cross-sector issues arise. The objective is to ensure that existing ECN/S rules continue to promote effective competition and end-user choice in the provision of connectivity for VW/Web 4 services.

6. Conclusions

The provision and full uptake of VW/Web 4 services sit at the crossroads of challenges typical of the ongoing industrial transition driven by cloudification and AI. The analysis, focused on the challenges faced by ECN/ECS during this transition, highlights some critical factors for scaling from legacy infrastructures to future connectivity – networks designed to deliver these services with high performance. Such advanced connectivity requires large investments in digital infrastructure, enhanced network management as well as the integration and orchestration with other digital assets (e.g. AI or distributed computing). In this context, complex relationships amongst market actors with asymmetric scale and bargaining power arise, entailing at the same

[122] EC has explicitly flagged this risk: without intervention, a few big tech companies could set de facto standards and control key platforms, which might lock in users and stifle competitors: Gatekeepers in Virtual Worlds – Competition Concerns – The European Commission's Web 4.0 Communication warned of large players possibly becoming gatekeepers of virtual worlds by exploiting network effects and setting closed standards. This mirrors concerns from past tech markets (e.g. social media, mobile OS) and underpins the importance of applying antitrust and DMA measures early. Ensuring interoperability and preventing lock-in are seen as key to avoiding monopolization of the emerging metaverse space.

time cooperation, by means of multiple partnerships, as well as competition dynamics. The main difficulties faced by ENC/S providers reflect uncertainty about demand trajectories, investment incentives, RoI, viable business models, and the capture of added value.

From a regulatory perspective, this evolution requires to foster investments, ensure openness and competition while preserving sectoral end users' rights within a multilayered, multi-stakeholder ecosystem. Regulation relies on the EU Digital Rulebook that, among others, will include the DNA, the tabled Regulation intended to reform, inter alia, the EECC, which currently provides a robust pro-competitive framework and toolkit to promote, *ex ante,* competition, investment in advanced connectivity, and openness.

Furthermore, timely availability of suitable spectrum bands, alongside efficient assignment and sharing, is necessary to avoid distortions to competition and associated welfare losses. These themes are persistent because, as mentioned, the value chains of VW/Web 4 services are characterised by strong network effects and the presence of large platform players. Therefore, openness proves essential at both the network layer (internet access services) and the platform layer to the extent of promoting market contestability.

From the sectoral user rights' perspective, inclusion, openness, and interoperability are critical. Additional public-policy concerns arise around cybersecurity, environmental sustainability and privacy.

In this fully fledged context, regulators are called to provide predictability, preserve openness and portability, monitor emerging bottlenecks, and promote a competitive, technology-neutral and consumer-friendly virtual worlds ecosystem.

ANNEX I. GENERAL CHALLENGES

1. The need for Interoperability and standardization

Interoperability

There is a challenge to implement interoperable protocols required not only to enable seamless user and data exchange across virtual environments and consumer devices, but also to support cross-platform integration — facilitating, for instance, the transition to Web 4 and “Industry 4.0”. Such interoperability would enable new use cases, for example, to use wearables to reliably share contextual user data (e.g. biometrics, presence, activity) with home automation systems to allow adaptive responses like dynamic lighting, HVAC regulation, or health alerts. Otherwise, in VWs, both businesses and consumers would face vendor lock-in due to the inability to transfer digital identities, devices (e.g., head mounted devices (HMDs)), avatars, or digital assets between platforms. For industrial clients, a lack of interoperability can also compromise efficient load balancing and energy management, as unified device discovery, control, and monitoring become fragmented.

Interoperability in the context of VW/Web 4 could be considered at different layers of the ecosystem, for example, between devices and VW, VW and applications or between the different VWs.

From a technical perspective, interoperability is enabled by standardized data exchange protocols, seamless API integration, and coherent semantic interpretation across diverse devices and systems, ensuring functional cohesion in increasingly complex digital ecosystems.

However, achieving interoperability is difficult because platforms often use proprietary technologies and lack shared protocols, and this concerns especially the domain of IoT. Indeed, current VWs as, in general, digital services, are technologically fragmented.

The telco sector is not concerned by all these layers but as VWs are enabled by their critical work on the infrastructure level, they play a role in leveraging interoperability and standardization, where applicable.

Regarding the development of NaaS-based solutions, a lack of standardization would limit innovation and market opportunities. In contrast, supporting open APIs could: i) position them as key digital enablers; ii) enable new services like identity management and seamless platform connectivity; iii) enable their upward scaling and significantly enhance the B2B and B2C experience and overall welfare of their clients. Therefore, telcos are active in several initiatives to enhance standardization.

Furthermore, some VR devices are currently locked to a use generally limited to a single platform, the one provided by the manufacturer. This technical and economic barrier could mean that individuals stack different immersive devices with similar functionalities in order to access the different platforms, thus multiplying the environmental impacts of the manufacturing of each device. It is important to avoid this scenario by requiring interoperability of physical devices.

Mesing *et al.*[123] proposed a framework for the interoperability of virtual reality solutions as early as 2008.

In this context, interoperability at the device level should be considered as a lever to limit the environmental footprint of the sector (see below) but also to allow users not to be locked in in a particular platform by their device.

Standardization

Nevertheless, BEREC notes that the industry is already doing some efforts to create standards for VWs[124]. These efforts should be pursued, in a multistakeholder approach, so end users' needs for instance are considered.

BEREC has a tight list of projects and programmes that explicitly mention Metaverse / XR / Virtual Worlds / Web 4 and have a direct connection to network APIs (standardisation, exposure, or pilots). (Each initiative hyperlinks its source) in the following table:

Table 6 Main projects and programmes related to metaverse and involving ECN/S

3GPP — Study on Application Enablement Architecture for *Mobile Metaverse* Services (TR 23.700-21)	Defines how applications can use 3GPP exposure (CAPIF/NEF/SEAL) to obtain and control network capabilities specifically for mobile metaverse scenarios. Status: Release-19 study item with active security follow-ups. (3GPP Portal)
ITU-T Focus Group on Metaverse (FG-MV)	A dedicated programme analysing network requirements and enablers for the metaverse (QoS/QoE, reliability, etc.), with technical reports you can cite in policy or trials. (ITU)
Telecom Infra Project (TIP) — Metaverse-Ready Networks Project Group	Industry working group (operators + hyperscalers) to evolve networks for metaverse-class services, emphasising programmability and new capabilities exposed via APIs. (Telecom Infra Project)
TM Forum Catalyst — "How Open APIs are the building blocks for a 5G *metaverse*"	A multi-member Catalyst showing interoperability between TM Forum Open APIs, CAMARA, and GSMA Open Gateway with explicit metaverse aims and demonstrators. (inform.tmforum.org)
Metaverse Standards Forum — Network Requirements & Capabilities to Support Metaverse Applications	Cross-industry technical paper that names network APIs (e.g., CAMARA) as part of the metaverse stack and maps requirements that network API projects should meet. (portal.metaverse-standards.org)
GSMA Open Gateway — Operator Network APIs with XR/Metaverse use cases	• Use-case library (incl. Quality-on-Demand) highlighting low-latency/assured experiences relevant to XR/metaverse. (GSMA) • Telefónica Open Gateway "Media, Entertainment & XR" solution area (developer materials, API usage). (Telefónica Open Gateway) • Vodafone: Open Gateway positioned as a catalyst for immersive communications, Web3 and metaverse services. (Vodafone.com)

[123] The USE-VR Platform - A Framework for Interoperability among Different VR Solutions
[124] ETSI Augmented Reality Framework (ARF); Virtual World Standards Landscape Report

Real-world pilot — MATSUKO holographic presence using QoD network APIs (Metaverse/XR)	Demonstrated at MWC using GSMA Open Gateway QoD via Azure Programmable Connectivity to improve hologram quality and stability—an explicit XR/metaverse application consuming network APIs. (Amdocs)
EU Web 4.0 & Virtual Worlds strategy — policy frame backing API-driven infrastructure	While not a technical spec, this is the EU policy anchor for Web 4/virtual worlds that underpins interoperable, open network capabilities and trials in Europe (useful for regulatory context and funding alignment). (EUR-Lex)
SNS/HE projects with explicit XR/Metaverse focus and network enablers/APIs	6G-XR (SNS JU) — experimental research infrastructure for next-gen XR services and network enablers/platform APIs for trials. (6G-XR)

Table 7 SDOs for the metaverse

Layer	Key SDO activity
3D Media & Assets	Metaverse Standards Forum, Khronos Group, W3C (WebXR, glTF, USD)
Digital Identity & Avatars	W3C, ISO/ITU, Metaverse Standards Forum (avatar interoperability, identity portability)
Networking & Geo-Spatial	ETSI ARF, OGC, Metaverse Standards Forum ("Network Requirements")
Data Spaces & Digital Assets	ISO/IEC 23751 (Data Sharing), 22123 (Cloud), Blockchain/DLT standards
AI & IoT Integration	ITU AI/IoT standards, ISO/IEC work on federated AI, Digital Twins
Accessibility & Ethics	W3C (WAI), Metaverse Forum Accessibility, ITU ethical guidelines

One institutional initiative set up to map and promote the main advancements for standardisation and interoperability in the ICT sector (part of the Annual Union Work Programme) is the annual Rolling Plan,[125] available for 2025: section 3.3.7, dedicated to VW/Web 4, identifies 7 key areas for interoperability and standardisation provided for in the table below.

[125] The Report describes EU policy-driven priorities and guidance to SDOs for standardisation activities that support key EU digital policies.

Table 8 key areas for interoperability and standardisation of VWs/Web 4

Layer	Building blocks in Staff Working Document (technical trends)
Virtual economy & society	• 4.13 Digital identity • 4.7.1 Blockchain, 4.7.2 Non-fungible tokens (NFTs)
Virtual experiences	• 4.6 Digital Twins • 4.8.3 3D technology, 4.8.5 Authoring tools, 4.8.6 Avatars • 4.9.3 AI agents and virtual beings
Human Interfaces & AR/VR devices	• 4.8.1 Virtual reality and augmented reality • 4.8.7 Human-Computer Interfaces (HCIs) • 4.10 Electronics and photonics
Reality capturing	• 4.8.4 Positioning technology • 4.11 Internet of things, 4.12 Artificial Intelligence of Things
Artificial intelligence	• 4.9.1 Machine learning, Deep Learning and Generative AI • 4.9.2 Language Technologies and Natural Language
Data	• 4.5 Data
Infrastructure	• 4.3.1 Networks, 4.3.2 5G/6G • 4.4.1 Cloud computing, 4.4.2 Edge computing, 4.4.3 High Performance Computing, 4.4.4 Quantum

Source: The EC Rolling Plan

For ECN/ECS operators, active participation in the fora which promote standardisation and interoperability presents opportunities to influence emerging standards directly, ensuring they align with ECNs' capabilities and operators' business models. But as it was noted before, it is important to pay attention to the opportunities the small players have to fully participate in these forums and help create standards that do not benefit only the biggest players.

Last, but not least, standardisation does have impacts on end-users' rights, societal inclusion or environmental sustainability (see below).

2. End-user rights and social inclusion

As in several markets or sectors, it is a challenge guarantying end-user rights and social inclusion in the innovative and emergent VW/Web 4 ecosystem. In order to ensure inclusion in VW/Web 4, there must exist support to accessibility, user protection, and social diversity.

Accessibility: Systems and services should support advanced interaction (voice, haptics) for users with disabilities. Collaboration and compliance with EU accessibility laws (e.g., EAA, Web Accessibility Directive) are essential.

User Protection: Secure connectivity and privacy-compliant data flows under GDPR and future regulations are necessary, addressing risks like harassment and biometric data misuse, including the identification of an appropriate supervision and legal/regulatory enforcement authority (cf. Section 4 below about jurisdiction and enforcement challenges).

Inclusion: It should be promoted affordable, wide-reaching connectivity and digital literacy to prevent digital divides, especially for marginalized groups. This aligns with EU policy goals and offers reputational and market benefits.

3. Environmental Sustainability

There are challenges related to the environmental sustainability of particular VW/Web 4 use cases. Following the European Green Deal, assessing and reducing the environmental impact has been an important objective, including in the telecommunications sector. ARCEP for example produced comprehensive reports to assess the digital environmental footprint[126]. Also, ADEME and ARCEP have identified the risk of a tripling of the carbon footprint between 2020 and 2050[127]. VW, as a digital service, has also its own environmental footprint.

Standardisation organisations such as ITU or IEEE[128] are working on methodologies tailored for assessing VWs' environmental impact, and some data is already available.

As already noted by BEREC in its response to the EC consultation on Generative AI and Virtual Worlds[129], the entire lifecycle of VWs should be considered when it comes to its environmental footprint, including manufacturing of devices: virtual worlds tend to be paired with the use of a dedicated device (for instance: VR headsets). This characteristic can be problematic in an environmental perspective: devices – especially their manufacturing – constitute the majority of the ICT sector environmental impact (between 60-80% of GHG emissions of the ICT sector)[130].

VW also rely on infrastructure such as data centres and networks which have their own environmental impact[131]. With regard to the impact on data centres, the operation of immersive virtual worlds requires servers, which consume a great deal of energy[132]. With regard to the impact on networks, the identified risk is due to an increase in the load on mobile networks, which are expected to support mobile use of immersive virtual worlds with low latency and high throughput requirements[133]. The risk is also linked to the potential for network congestion, which could lead to service interruptions or delays[134].

As VW/Web 4 have a huge innovative potential, an innovative strategy embedding the environmental considerations is recommended. There could be benefits for VW to be sustainable-by-design.

4. Jurisdiction and enforcement challenges

The inherently borderless nature of VW/Web 4 introduces significant jurisdictional complexities for regulators and enforcement authorities.

Addressing these cross-border and decentralisation challenges requires robust international cooperation. Global coordination through forums such as the G20, OECD, ITU, and the Council

[126] *Numérique et environnement* ARCEP, 2025 (in French)
[127] ADEME-Arcep study: assessment of the digital environmental footprint in France in 2020, 2030 and 2050, ADEME, ARCEP, 2025
[128] https://ieeexplore.ieee.org/abstract/document/10012292
[129] BEREC high-level position on artificial intelligence and virtual worlds
[130] BEREC External Sustainability Study on Environmental impact of electronic communications
[131] BoR (26) 01 External study on data centres https://www.berec.europa.eu/en/all-documents/berec/reports/external-study-on-data-centres; ADEME-Arcep study: assessment of the digital environmental footprint in France in 2020, 2030 and 2050, ADEME, ARCEP, 2025
[132] CEPIR project, 2024
[133] The Shift Project, What virtual worlds for a sustainable real world?, 2024
[134] ibid

of Europe can help harmonise legal standards and establish mutual recognition frameworks, mitigating risks of jurisdictional fragmentation. Key collaborative areas include standardisation, interoperability, law enforcement, consumer protection, and taxation. Effective governance thus necessitates adaptive and multistakeholder frameworks, combining international norms with local regulatory autonomy. This can imply for stakeholders like BEREC to reinforce their capacity to foster consistent implementation across Member States.

5. Interaction with EU Regulatory Frameworks and instruments

One future challenge for regulators in the future governance of VW/Web 4 is guaranteeing consistent interaction between the diverse pillars of EU Regulatory Frameworks and instruments for the digital acquis, collectively referred to as the Digital Rulebook[135].This is a European robust set of digital regulations which intersect also VWs and serve as a foundation for their governance. Key regulatory frameworks include: the Digital Networks Act (DNA), intended to reform the EECC, the Digital Services Act (DSA)[136], Digital Markets Act (DMA)[137], General Data Protection Regulation (GDPR)[138], the Data Governance Act (DGA) and Data Act (DA)[139], and the Artificial Intelligence Act (AI Act)[140]. These collectively – together with consumer protection laws and several other regulations[141] – address core issues such as platform accountability, fair competition, data privacy, and trustworthy AI deployment, providing a comprehensive framework which, to a certain extent and selectively, that is also according to cases, can factor in the offer of emerging VW/Web 4 services.

In summary, the EU's regulatory toolkit – from digital markets and services regulation to data, AI, consumer, and sectoral laws – provides a comprehensive starting point to govern Web 4 and virtual worlds. However, given the novel aspects of VW/Web 4, stakeholders have highlighted certain areas where further clarification/guidance or targeted adaptation may be beneficial. For

[135] See An agile Digital Rulebook for the EU | Shaping Europe's digital future).
[136] Which establishes a comprehensive system of accountability for online platforms and intermediary services providers. The DSA's rules (e.g. notice-and-action for illegal content, transparency obligations, and risk mitigation for very large online platforms) will apply to platforms operating virtual worlds insofar as they store or disseminate user generated content. The DSA guarantees for content legality and protection of users' rights apply equally within immersive/virtual environment. online, including, immersive, environments.
[137] Imposes ex ante obligations on "gatekeepers" to ensure open and fair digital markets. If certain virtual world platforms were to meet the DMA designation thresholds, or, more realistically, if the gatekeeper integrates or embeds them in their CPS, then the applicability of the DMA could be considered, analogously to the scenario triggered by the embedment of AI tools, see *the DMA High-Level Group statement on AI at https://digital-markets-act.ec.europa.eu/high-level-group-digital-markets-act-public-statement-artificial-intelligence-2024-05-22_en*.
[138] Applies fully to personal data processing in virtual worlds, which can generate large volumes of personal data (such as biometric identifiers, gaze tracking, location, social interactions). GDPR ensures that users have rights over this data (access, deletion, etc.) and that entities processing it must have a legal basis and abide by principles like data minimization and privacy by design. Enforcement in a virtual context may require cooperation among Data Protection Authorities due to cross-border operations.
[139] This regulation establishes a framework for data sharing and user control over data, which can impact virtual world services. This act also aims to break down data silos, which may foster innovation in virtual worlds and also addresses cloud switching and interoperability.
[140] The AI Act regulates AI systems based on risk, and this will cover AI used within virtual worlds. For example, AI-driven virtual characters (bots), content-generation algorithms, or content moderation tools in a VR platform might be subject to transparency or safety requirements if they pose risks.
[141] As the Markets in Crypto-Assets (MiCA) Regulation, the European Digital Identity (EUDI) Framework, European Accessibility Act (EAA) and Web Accessibility Directive, or the European Media Freedom Act.

instance, specific interpretative guidance could clarify how the GDPR applies to immersive environments that extensively collect biometric or behavioural data. Similarly, the DSA's provisions for platform accountability may need further detail to address content moderation challenges unique to real-time interactions within immersive virtual settings.

There is an acknowledged need for ongoing assessment to ensure these regulations are implemented consistently, remain fit-for-purpose and effectively balance market innovation and consumer protection. In line with this, the European Parliament's January 2024 resolution on virtual worlds endorsed the EU's current digital framework but has called for proactive analysis and urged continued evaluation.[142]

6. Competition and collaborative market oversight in VW/Web 4

The rapid evolution of the metaverse presents significant challenges for monitoring potential market concentration across various ecosystem layers. The outcome of the Global multistakeholder high-level governance conference[143] echoed that sentiment: fair competition must be ensured by tackling concentration and avoiding closed ecosystems. The conference outcome also stressed that interoperability is key for competition, as it lowers entry barriers.

Stakeholders emphasize interoperability as a fundamental regulatory principle to prevent monopolistic market segmentation. Establishing interoperability standards and regulatory sandboxes[144] (or testbeds) is recommended to encourage open platforms and facilitate market entry by new participants, but also to avoid market partitioning and segmentation.

Vertical integration raises particular concerns, notably around self-preferencing. Companies controlling hardware, platforms, and content simultaneously might unfairly advantage their services. Regulators, including NRAs, should proactively monitor early signs of self-preferencing, especially when these affect network quality or interoperability.

Leverage of market power from adjacent services dominated by integrated players also requires careful oversight.

[142] https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2022/2198(INI)&l=en.

[143] 'Outcome document' of the Global Multistakeholder High Level Conference on Governance of Web 4.0 and Virtual Worlds | Shaping Europe's digital future.

[144] Where companies and regulators can experiment with interoperability solutions and data portability in a controlled way. These could inform future regulations if voluntary measures don't suffice.

ANNEX II. SELECTED 'USE CASES' AND THEIR IMPACT ON THE EC SECTOR

To illustrate the possible implications of VW/Web 4 for the electronic communications sector, we set the focus on a set of notable use cases that may be particularly relevant[145]. For each, we assess their potential impact and highlight the challenges that NRAs and BEREC may need to address:

1. Urban digital twins ("Cityverse")

Description & Impact: City-wide digital twins create immersive, real-time virtual replicas of urban environments for planning, infrastructure management, and citizen services. They integrate massive IoT sensor data and high-definition 3D models to simulate traffic, utilities, and public spaces, which can improve city planning and disaster response.

Network implications: This use case drives significant network capacity demands and low-latency requirements, as vast amounts of real-time data must be collected, processed, and fed back into the virtual city model. Multi-access edge computing is often needed at the network edge (near city data sources) to achieve the responsiveness and scalability required.

Regulatory challenges: Urban digital twins will only succeed with *open standards, interoperability, robust governance, and security frameworks*. NRAs and BEREC could encourage standardized data formats and interoperability across platforms so that "cityverse" services are not siloed by vendor, ensuring a level playing field and fostering the EU single market[146]. They also might need to consider data governance and privacy (given the sensitivity of real-time city data) and promote investments in VHCN (e.g., 5G SA and 6G in the future, fibre) and edge nodes to support these services. Close cooperation with municipal authorities and *multi-stakeholder governance* will be key to address cybersecurity and resilience issues in city-scale digital twin deployments.

Some VW applications entail the collection, transmission and processing of a great amount of data at a minimum delay implying, in terms of connectivity, the provision of high-bandwidth, low latency and resilient networks able to cope with the corresponding traffic increases.

2. Industrial virtual worlds (Industrial digital twins)

Description & Impact: In industrial settings (manufacturing, energy, logistics), VW are used to create digital twins of factories, machines, and processes. These enable advanced applications like predictive maintenance, process optimization, and remote operations. For example, a factory

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[145] See ITU, "Citiverse Use Case Taxonomy Overview – Use Case Identification Track",

146 The Networked Local Digital Twins towards the CitiVERSE (LDT CitiVERSE EDIC) initiative aims to connect existing local digital twins across Europe, forming the basis for the EU CitiVERSE. See the EC Implementing Decision setting up the EDIC (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202400459).

digital twin can simulate production runs to optimize efficiency, or a heavy machinery twin can allow remote experts to troubleshoot issues in real time. The impact is substantial gains in productivity, reduced downtime, and safer operations by testing changes virtually before physical implementation[147].

Network implications: Industrial VW rely on **dedicated, high-reliability connectivity** – often private 5G networks or network slicing – to link sensors, robots, and AR/VR devices with low latency. Edge computing is critical: processing data on-site or nearby allows **rapid response** for control systems[148]. For instance, deploying AI at the edge can help resolve robotic malfunctions within milliseconds and allow real-time consultation with remote experts across facilities.

Regulatory challenges: NRAs may need to adapt spectrum policy to facilitate **private industrial networks** (e.g. local 5G licenses for factories), ensuring these networks meet ultra-reliability standards. There is a challenge of interoperability between public networks and private industrial systems – BEREC could help on defining guidelines so that industrial IoT and VW/Web 4 platforms use common, open interfaces (also preventing vendor lock-in) – the Data Act already contains obligations for access and sharing of data generated from connected devices (e.g. IoT). Security is paramount: regulators should promote *security-by-design* in industrial IoT/VW deployments (protecting critical infrastructure from cyber threats). Additionally, as ECN operators increasingly offer "Industry 4.0" connectivity solutions, competition issues could arise (e.g., big industrial platforms vs. traditional telcos).

3. Immersive remote collaboration & telemedicine

Description & Impact: This use case covers virtual workspaces and remote expert services, ranging from VR-based business meetings to AR-supported telemedicine. Immersive collaboration tools allow teams or individuals in different locations to meet "face-to-face" as avatars or holograms in shared virtual environments, boosting engagement compared to traditional video calls. In healthcare, specialists can consult or even guide procedures remotely via AR/VR (e.g. a surgeon offering remote assistance using a live 3D view). These applications can greatly expand access to expertise (no matter distance) and reduce the need for travel, benefitting productivity and inclusiveness (e.g., home-bound patients or remote workers).

Network implications: Such services are **latency-sensitive and bandwidth-intensive**. To feel truly synchronous and lifelike, they require *very low latency* and stable high-throughput links, especially for high-definition video or haptic feedback. In critical cases like remote surgery or emergency response, networks must be *ultra-reliable*. For example, a connected telehealth solution for vulnerable patients demands **highly robust and reliable connectivity** available throughout the patient's location[149]. Any network impairment (e.g., delay, packet loss, or outage) may degrade performance or, in life-critical scenarios, could have safety implications.

Regulatory challenges: BEREC and NRAs could support consistent approaches (e.g. on QoS measurement/monitoring practices and transparency) for real-time immersive services in

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[147] See e.g. ITU Focus Group on the Metaverse (FG-MV), "Exploring the metaverse: opportunities and challenges",
[148] See ETSI's edge computing standardisation overview
[149] See e.g. GSMA, "Connected in-home care for vulnerable patients" (case study).

coordination with ongoing BEREC work under the Open Internet framework. At the same time, it must be ensured that prioritization is non-discriminatory and transparent. Privacy and data security are also critical – strict protections for the **sensitive personal data** involved in virtual meetings or medical consults (aligning with GDPR and healthcare data standards) should be in place. In addition, the allocation of responsibilities (including liability) across operators, platforms and service providers – particularly where premium QoS tiers or SLAs are marketed – may warrant attention as part of broader risk management and consumer protection. Finally, to foster widespread adoption, NRAs might promote access policies so that sufficient broadband coverage exists even in rural areas and or for disadvantaged populations, ensuring these advanced services don't deepen the digital divide.

4. Immersive entertainment (gaming and virtual events)

Description & Impact: Entertainment is a driving force behind VW adoption. This category includes **VR/AR gaming**, virtual concerts, sports events, and other immersive media experiences. Users can play games in fully virtual reality or attend live events via avatars, often interacting with others socially in these environments.

Network implications: The impact on our sector is significant because these applications generate *intense demand for data* and put new stress on ECN. A popular VR game or a virtual concert with thousands of attendees requires streaming high-resolution, real-time (3D) content to many users simultaneously. Current trends already show that cloud-based gaming and VR streaming can push the limits of networks: for instance, a high-quality cloud VR gaming experience could require latency below 10 ms and on the order of 1 Gbps bandwidth *per user* – far beyond typical video streaming[150]. Even today, achieving <20 ms latency is considered necessary for a good interactive gaming experience, and baseline cloud gaming services need ~35–50 Mbps[151]. As immersive media quality rises (e.g., adding haptic feedback or ultra-HD visuals), the data rates and performance demands will rise accordingly.

Regulatory challenges: The gaming industry, a key driver of the metaverse's evolution, is gaining additional momentum and merits special attention. The surge in data traffic from these services can strain networks, requiring that network operators continue to invest in capacity (e.g., 5G/6G, fibre, Wi-Fi 7 and beyond) and possibly edge caching, to handle peak loads without causing congestion for (other) users. In such a context, ECN operators are developing network capabilities to boost real-time gameplay and cross-platform services, while partnering with cloud-gaming platforms/publishers, device Original Equipment Manufacturers (OEMs) (handset/console makers), cloud/edge and CDN providers, and e-sports/event platforms to offer bundled deals[152]. Regulators should monitor how operators manage such traffic: Open Internet Regulation obligations apply; traffic management and any prioritisation (e.g. of specific gaming or VR traffic) would need to remain within the Regulation's conditions and be transparent, proportionate, and

[150] DE-CIX (CTO), "Immersive Internet" (quantitative discussion of very low latency and high-end 8K VR, and cloud gaming baseline throughput).
[151] Ibidem.
[152] This shift is accelerating globally, including, particularly, in Southeast Asia: https://www.kearney.com/industry/communications/article/-/insights/mobile-gaming-how-sea-telcos-can-unlock-a-unique-opportunity.

non-discriminatory. Given the potential extreme QoS needs, there might be discussions about treating certain immersive experiences as *specialized services*. BEREC and NRAs should monitor developments and support consistent application of the Open Internet framework (including permissible traffic management). Consumer protection/transparency is another angle: ensuring that advertised speeds and latency for “gaming-grade” or “VR-ready” broadband are accurate, and that users are informed of data usage and any additional costs.

5. Tele-operated mobility (remote vehicles and drones)

Description & Impact: This emerging use case involves remotely controlling physical vehicles, such as cars, trucks, or drones, via wireless networks and virtual interfaces. In practice, an operator could sit in a control centre (wearing VR goggles or using a console) and drive a vehicle on the road or pilot a drone as if on-site. Such tele-operation can enable new services – for example, drone deliveries, remote bus or truck driving in dangerous areas, or assisting autonomous vehicles when they get into tricky situations. It also has public safety applications (e.g., operating robots or vehicles in disaster zones). The impact on our sector may be the creation of *mission-critical communication needs* that extend the role of ECN into transportation.

Network implications: Tele-operated driving demands **low latency** and *extreme reliability*. Any control command from the remote driver must reach the vehicle almost instantly, and live video/feedback from the vehicle must stream back with minimal delay; otherwise, safe control is impossible. According to industry requirements, round-trip (end-to-end application) latencies on the order of 100-200 ms (or even lower) are needed for driving[153]. In addition, the service requires extremely high network availability (*99.999% availability* targets) and ultra-reliable low-latency communication, URLLC, capabilities may be required to meet reliability and latency targets. Bandwidth is secondary to latency here, but high-quality video feeds (360° cameras on a car, for instance) still require a fairly large and steady throughput[154].

Regulatory challenges: Tele-operated mobility blurs boundaries between telecom and transport regulation. Coordination with transport authorities will be needed to develop certification that a given “network service is safe for remote driving”. NRAs could push for **coverage obligations** (along priority corridors/specific road classes relevant to the service, subject to proportionality and national frameworks) and possibly e.g. dedicate licensed spectrum for V2X (vehicle-to-everything) communications[155]. One challenge is cross-border or inter-network handover: a remotely driven vehicle might traverse different (mobile) networks – and it may need to be ensured seamless roaming agreements or common QoS standards across operators for such services. Security is also paramount: the communication link must be protected from interference or hacking (to prevent takeovers of vehicles), implying enforcement of strong encryption and possibly certification of network equipment for these uses. Finally, liability and service-level agreements will be an issue – regulators might contribute to ensure consumers are informed

[153] 5GAA White paper, “Tele-operated Driving: Use Cases, System Architecture and Business Considerations” (latency and service requirements).

[154] While control signalling is typically low-bit-rate but highly latency-sensitive (downlink towards the vehicle), the uplink (vehicle-to-control-centre) often dominates throughput due to multiple real-time video and sensor streams; the exact bandwidth depends on sensor modality, resolution and redundancy.

[155] See Commission Decision 2008/671/EC (harmonised use of the 5.9 GHz band for ITS safety-related applications) and ECC Decision (08)01 (CEPT/ECC harmonisation in 5.9 GHz ITS band).

about the scope and constraints of these services (e.g., geographic availability/coverage and conditions under which service continuity cannot be guaranteed). In summary, enabling tele-operated mobility will require close alignment between the regulatory frameworks and automotive safety requirements, an area where BEREC and NRAs can play a facilitating role.

6. Immersive education and training

Description & Impact: VW are also being applied in education and professional training. Examples range from virtual classrooms where students can engage with 3D content and simulations, to workforce training programs using VR/AR (for instance, training pilots in a virtual cockpit or factory workers practicing assembly of equipment in AR). Immersive education can make learning more engaging and accessible – students or trainees can experience scenarios that would be impossible or too costly in real life. This leads to improved learning outcomes and skills transfer (learning by doing in safe virtual environments). For industries, it means faster, more effective onboarding and upskilling of employees, often at lower cost and with fewer safety risks.

Network implications: To support distributed VR classrooms or training modules, **ubiquitous high-bandwidth connectivity** is needed so that all participants (whether at home, school, or a training centre) can access the content seamlessly. Real-time interaction in a virtual lab or training simulation demands low latency (to allow responsive feedback) and enough bandwidth for rich media. For instance, an industrial training simulation might involve detailed 3D graphics and live instructor feedback, similar in demands to an immersive game. If training is done remotely, the network must handle potentially many concurrent users (e.g., a class of trainees) in a synchronized virtual environment.

Regulatory Challenges: The key concern here is **inclusion and equal access**. BEREC and NRAs could help to avoid a scenario where only certain schools or regions (or population) can benefit from immersive education due to connectivity gaps. This means continuing promoting efforts to close the urban-rural broadband divide (ensuring fibre and/or high-speed 5G reaches schools and households in all areas). They may also help promoting specific (public) connectivity programs (in collaboration with other bodies) for educational institutions to get the necessary bandwidth. Interoperability standards are also beneficial here – so that an educational VR platform isn't locked to one operator or device type, e.g. by advocating open standards (as with other use cases) and perhaps supporting **EU-wide platforms or federations** for educational content. Finally, data privacy must be maintained (students' data and interactions in virtual classrooms should be protected under GDPR and educational privacy rules). Overall, the role of regulators is to make sure that the transformative benefits of VR/AR in learning can be realized broadly, safely, and in a competitive ecosystem of providers.

Each of these use cases demonstrates a different facet of how VW/Web 4 innovations could drive network evolution and pose challenges and regulatory questions. BEREC and NRAs will need to proactively address these to foster innovation while safeguarding connectivity, competition, and end-user rights. By focusing on targeted scenarios like the ones above, regulators can identify where existing frameworks suffice and where new approaches or guidelines may be required – ensuring readiness to support these emerging digital experiences.

ANNEX III. NETWORK PERFORMANCE

1. Current Network Performance

Some VW applications entail the collection, transmission and processing of a great amount of data at a minimum delay implying, in terms of connectivity, the provision of high-bandwidth, low latency and resilient networks able to cope with the corresponding traffic increases.

VHCN can be taken as a reference to the performance of current advanced connectivity as networks capable of providing end users with a particularly high QoS. In this regard, BEREC Guidelines on Very High-Capacity Networks[156] define the following performance thresholds that VHCN shall be able to provide at peak time:

Table 9 - VHCN networks performance thresholds

	Fixed	***Wireless***
Downlink data rate	≥ 1000 Mbps	≥ 350 Mbps
Uplink data rate	≥ 200 Mbps	≥ 50 Mbps
IP packet error ratio (Y.1540)	≤ 0.05%	≤ 0.01%
IP packet loss ratio (Y.1540)	≤ 0.0025%	≤ 0.01%
Round-trip IP packet delay (RFC 2681)	≤ 10 ms	≤ 18 ms
IP packet delay variation (RFC 3393)	≤ 2 ms	≤ 5 ms
IP service availability (Y.1540)	≥ 99.9% per year	≥ 99.9% per year

Source: BEREC Guidelines on Very High-Capacity Networks (2025)

These parameters refer to the achievable QoS at the network termination point (NTP) and, thus, do not take into account limitations such as the ones caused by the customer's premises equipment, the device or limited indoors coverage that significantly determine the users' QoE. It is additionally clarified that latency increases depending on the distance from the user to the point to handover.

Moreover, while the BEREC Guidelines take a forward-looking approach, these parameters are defined in base of the information on the actual data and experience of network performance provided by the stakeholders. In this regard, BEREC notes the uncertainty expressed both by network operators and vendors on the end-user achievable QoS based on technologies that are still being developed and have not yet been deployed and tested in real networks. It is not possible to accurately determine the QoS that end-users will experience with technologies that will be deployed in networks only in the future.

The Network Requirements and Capabilities Working of the Metaverse standards forum has carried out a *Gap and Feasibility Analysis for Metaverse Services*[157] focusing on the different

[156] https://www.berec.europa.eu/en/all-documents/berec/regulatory-best-practices/guidelines/berec-guidelines-on-very-high-capacity-networks

[157] Gap and Feasibility Analysis for Metaverse Services. Metaverse Standards Forum (2024)

technologies currently used in the access network and in-premises/local connectivity and the actual test and network diagnosis based on Ookla's data[158].

This report concludes that fixed networks, fibre and cable (DOCSIS 3.1/4.0)[159], and 5G can cope with connectivity requirements to support some isolated metaverse services. The bottleneck would be rather in in-premises connectivity as WI-FI, the most extended technology at this moment, does not provide low enough latency (even in case of Wi-Fi 6/6E). To address scale deployments and WI-FI connectivity, traffic engineering is suggested. In particular, performance improvements by means of Low Latency, Low Loss, Scalable Throughput (L4S) are signalled.

2. Network Performance requirements for Virtual Worlds

Different studies develop on networks requisites to deliver VW and provide some hypothetical estimates. While there is consensus that stricter network requirements than today's will be needed, the concrete definition of QoS thresholds differ in the studies consulted by BEREC. An explanation for this is that the values provided vary depending on the VW use case considered; some focus on AR/VR solutions or *proto virtual worlds* scenarios while others have an even more forward-looking approach and consider more advanced and stringent scenarios such as sensing or holographic communications.

On one hand, some studies[160] conclude that the *Internet was not designed for high-bandwidth, peer-to-peer communication The lags, packet drops, and network unreliability witnessed in today's world would make the current state of infrastructure unsuitable for building an experience remotely resembling the Metaverse as envisioned.*

On the other hand, the Metaverse Standards Forum[161] considers that *today's state of the internet, on average, is sufficient to deliver most of the metaverse applications over the top, on both mobile and fixed infrastructure. In average, mobile networks may not be capable of serving most stringent and extreme case in terms of uplink throughput and latency but would be totally capable of handling most of the use-cases. However, those results do not reflect the state of the network when the connection is under maximum load*.

The analyses on network performance for VW mainly focus on three parameters: impact on data traffic; data rates and latency.

Data traffic

VW involve a continuous stream of interconnected data.

BEREC has recently looked at data traffic trends in the BEREC Report on the IP Interconnection Ecosystem[162]. Some of the key observations made by BEREC in this regard is that data continues to grow. However, for the time being, traffic growth continues to be mostly driven by video traffic. At the same time, BEREC underlines the increasing regionalisation of IP traffic, primarily driven by low-latency requirements and the consequential deployment of CDN caches inside IAS

[158] https://www.speedtest.net
[159] Although Gfast has not been analyzed in the report, it could probably fulfill the requirements.
[160] Metaverse and Money. Decrypting the Future (2022) Citi, developing on Matthew Ball (2022)
[161] Gap and Feasibility Analysis for Metaverse Services. Metaverse Standards Forum (2024)
[162] BEREC Report on the IP Interconnection ecosystem BoR (24) 177

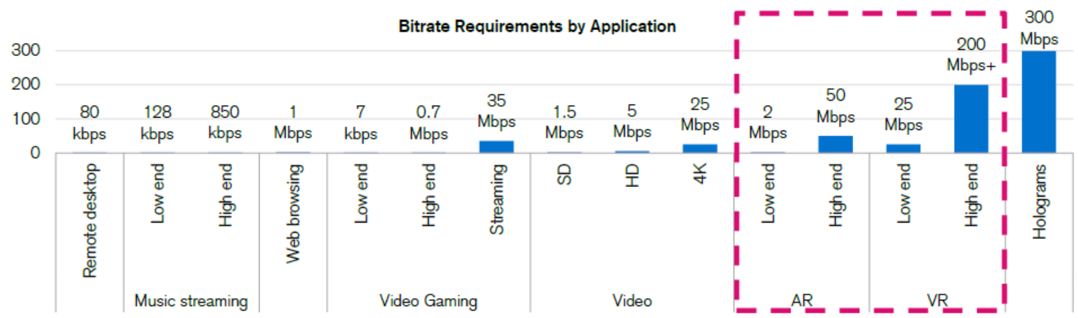
providers' networks or IXPs. The deployment of on-net caches allows for a reduction in backbone internet traffic, improves latency and, accordingly, QoE.

BEREC generally notices that the Internet has managed to cope with both traffic growth and higher peaks of traffic and trusts that the deployment of on-net CDNs and more efficient compression techniques are expected to offset the overall impact of further traffic growths.

Data rate

The general estimate of data rate made by Credit Suisse envisages a rather broad range (from 2 to 300Mbps) of the potential rates required.

Figure 1 Bitrate requirements by application



Source: Metaverse: A guide to the Next-Gen internet. Credit Suisse (2022)

A more recent report[163] estimates that MR and AR necessitate data rates ranging between 35 Mbps to 15 Gbps, while holographic communication requires substantially higher data rates, ranging from 1 to 10 Tbps[164].

Table 10 Metaverse network requirements.

	Video	VR	MR and AR	Holographic type communication
Data rate	35–100 Mbps	35–15 Gbps	35–15 Gbps	1–10 Tbps
Latency (high and low)	15–35 ms	~20 ms	~10 ms	<1 ms
Synchronization	Audio/video	Multiple tiles	Multiple tiles	Thousands (views/senses)
Devices	Smart devices and computers	HMDs	Smart glasses	Naked eyes/HMDs

Source: Exploring the convergence of Metaverse, Blockchain, and AI

The Metaverse standards forum provides a more specific analysis based on 8 use case scenarios[165] and concludes that around 80Mbps-DL/30Mbps-UL are needed for the most demanding applications analysed and 30Mbps-DL/10Mbps-UL would satisfy most of the cases.

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[163] Uddin, Mueen & Obaidat, Muath & Manickam, Selvakumar & Laghari, Shams Ul Arfeen & Dandoush, Abdulhalim & Ullah, Hidayat & Ullah, Syed Sajid. (2024). Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 14. 10.1002/widm.1556.
[164] Next-Generation Wireless: A Guide to the Fundamentals of 6G
[165] Network Requirements for Metaverse Services. Metaverse standards forum. The use cases considered are the following: Maintenance support; Avatar phoning; Local interaction with offloaded processing; Immersive telepresence;

Latency

Most reports underline the relevance of latency for immersive technologies. As developed in a recent article[166], *the failure of virtual experiences to truly replicate our senses introduces confusion in human brains, leading to symptoms like nausea, dizziness, and migraines. To mitigate these drawbacks, it is crucial to enhance the realism of virtual sensations and reduce latency in VR/AR devices, thereby minimizing latency between different modalities and avoiding its mismatch.*

As in previous parameters, again, the ranges vary in the different studies consulted according to the use cases considered. The following table summarizes and systematizes the inputs in the different reports consulted[167]:

Table 11 - Latency estimates on different use cases

USE CASE	ESTIMATED LATENCY REQUIRED
Round-trip latency for video calling/cloud gaming	75-150ms
Latency for multi-player complex games	Sub 30 ms
"standard" metaverse applications/VR – E.g. urban digital twins ("Cityverse")	Sub 20 ms / 20-25 ms
Truly immersive metaverse experiences, VR and AR – E.g. immersive entertainment (gaming/events) or immersive collaboration & telemedicine	Sub 12 ms / Sub 13 ms
Internet of senses – e.g. industrial VW (digital twins)	Sub 10 ms
Autonomous vehicles – e.g. tele-operated mobility (vehicles/ drones)	2 ms
Haptic and holographic communications	1 ms[168]

Source: BEREC elaboration base on different sources[169]

Immersive tele-operated driving; VR cloud gaming; Remote participation to a live entertainment event and AR whiteboard.

[166] N. Sehad, L. Bariah, W. Hamidouche, H. Hellaoui, R. Jäntti and M. Debbah, "Generative AI for Immersive Communication: The Next Frontier in Internet-of-Senses Through 6G," in IEEE Communications Magazine, vol. 63, no. 2, pp. 31-43, February 2025. Uddin, Mueen & Obaidat, Muath & Manickam, Selvakumar & Laghari, Shams Ul Arfeen & Dandoush, Abdulhalim & Ullah, Hidayat & Ullah, Syed Sajid. (2024). Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 14. 10.1002/widm.1556.

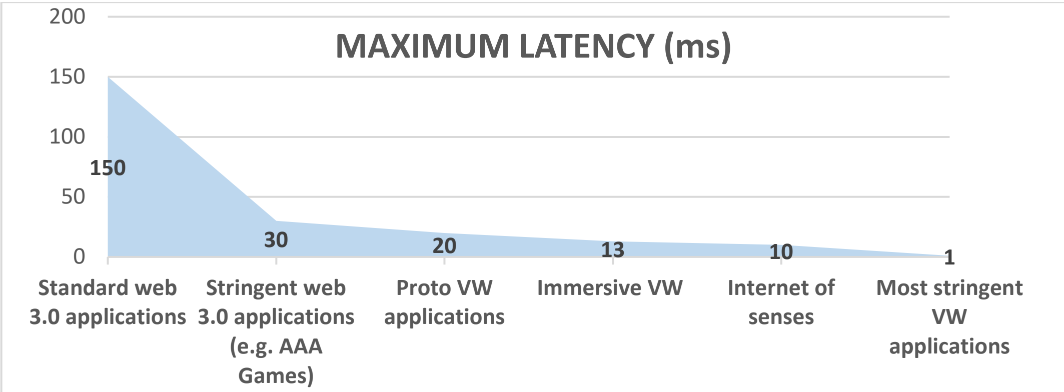
[167] These examples, coming from the literature review, are provided as a general proxy of the increased network demand for VW/Web4. Those estimates come from different sources that may follow diverse methodologies and assumptions. Moreover, some are just hypothetical as regard to future services.

[168] The latency requirement of 1ms was given in the context of tactile applications, with remote surgery given as use case. Reasons given for these requirements are lagged responses and motion sickness, which occur at higher latencies (see Cai, Yang et al., 2022. ‚Compute- and Data-Intensive Networks: The Key to the Metaverse'. https://arxiv.org/abs/2204.02001. Also, latency requirements of 1ms are expected for holographic communications according to Uddin, Muddin et al., 2024. ‚Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions' https://wires.onlinelibrary.wiley.com/doi/full/10.1002/widm.1556

[169] List of sources: Metaverse and Money. Decrypting the Future (2022) Citi; N. Sehad, L. Bariah, W. Hamidouche, H. Hellaoui, R. Jäntti and M. Debbah, "Generative AI for Immersive Communication: The Next Frontier in Internet-of-Senses Through 6G," in IEEE Communications Magazine, vol. 63, no. 2, pp. 31-43, February 2025; Y. Cai, J. Llorca, AM Tulino, AF. Molisch "Compute- and Data-Intensive Networks: The Key to the Metaverse" (2022); Network Requirements for Metaverse Services. Metaverse standards forum; S. Panwar. Breaking the Latency Barrier (2020).

These estimates allow providing a general reference to the evolution of latency requirements as digital services and applications are developed as shown in **Figure 2**.

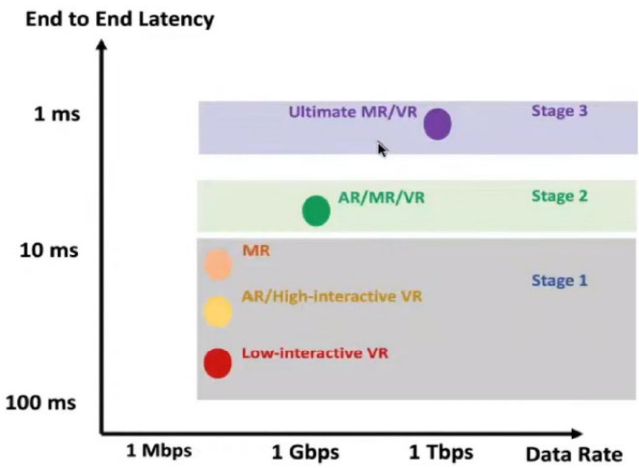
Figure 2 Latency for use case categories



Source: BEREC elaboration in base of different sources[170]

In base of the combination of data rates and latency requirements suggest[171] the evolution of connectivity towards VW in three stages (**Figure 3**).

Figure 3 - Latency and data rates for use case categories



Source: Exploring the convergence of Metaverse, Blockchain, and AI

[170] Ibid

[171] Uddin, Mueen & Obaidat, Muath & Manickam, Selvakumar & Laghari, Shams Ul Arfeen & Dandoush, Abdulhalim & Ullah, Hidayat & Ullah, Syed Sajid. (2024). Exploring the convergence of Metaverse, Blockchain, and AI: A comprehensive survey of enabling technologies, applications, challenges, and future directions. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 14. 10.1002/widm.1556.

ANNEX IV. NETWORK DEVELOPMENTS

This annex briefly outlines some of the main electronic communication networks developments relevant for VW evolution. Previous BEREC work addresses in detail technologies such as 5G, network virtualization and cloudification or the use of AI for the provision of ECN/S. We refer to these reports for a more comprehensive view on this matter.

a. WI-FI

Wi-Fi is broadly used to provide in-doors coverage and offload mobile traffic. In many cases, Wi-Fi complements fixed networks reaching the premises (or the room) allowing the wireless connection of devices in-premises. In this regard, the possibility for the end-user to fully benefit from the capabilities of fixed networks may depend as well in practice of the features provided by Wi-Fi connectivity.

The Metaverse Standards Forum indicates that WI-Fi 6E would benefit for further enhancement to better deliver VW applications. Along the same lines, researchers[172] pointed out that Wi-Fi had over the years improved peak throughput, capacity, and efficiency. However, the management of time-sensitive traffic with bounded low latency remained a problem that Wi- Fi 7 aims to address. WI-Fi 7 has been designed to provide ultralow latency, high data rates, and support a greater number of connected devices to enable the provision of real-time applications and XR. The main features provided by Wi-Fi 7 are summarized in **Figure 4**.

The IEEE published the Standard 802.11be or Wi-Fi 7 in July 2025[173]. Nonetheless, the Wi-Fi Alliance has already began certifying Wi-Fi 7 devices since January 2024[174]. Some ISP have already started to provide Wi-Fi 7 equipment in some countries since the end of 2024[175] or early 2025[176].

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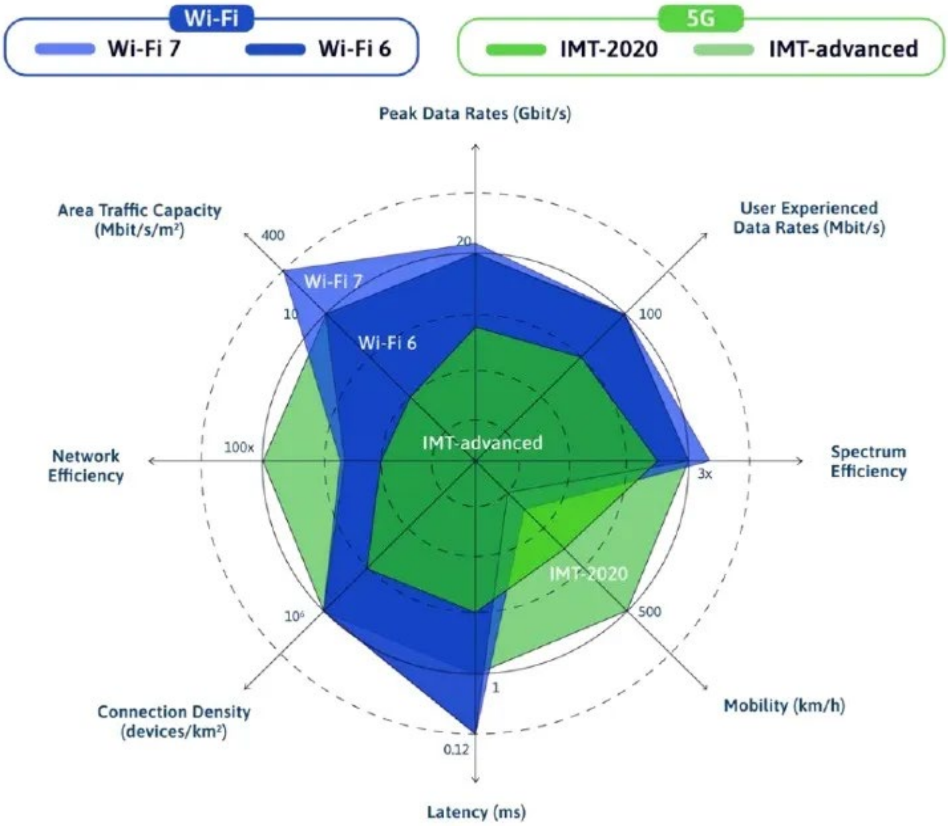
[172] Adame, T.; Carrascosa-Zamacois, M.; Bellalta, B. Time-Sensitive Networking in IEEE 802.11be: On the Way to Low-Latency WiFi 7. Sensors 2021, 21, 4954.
[173] See https://www.ieee802.org/11/Reports/802.11_Timelines.htm
[174] See https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-introduces-wi-fi-certified-7
[175] See https://blog.orange.es/producto/orange-revoluciona-de-nuevo-la-conectividad-de-sus-clientes-con-el-lanzamiento-de-su-router-wi-fi-7/
[176]See https://comunidad.movistar.es/t5/Bienvenida-y-Noticias/Movistar-anuncia-un-nuevo-router-con-WiFi-7-y-la-actualizaci%C3%B3n/td-p/5230796

Figure 4 - WI-FI 7 and 5G Performance



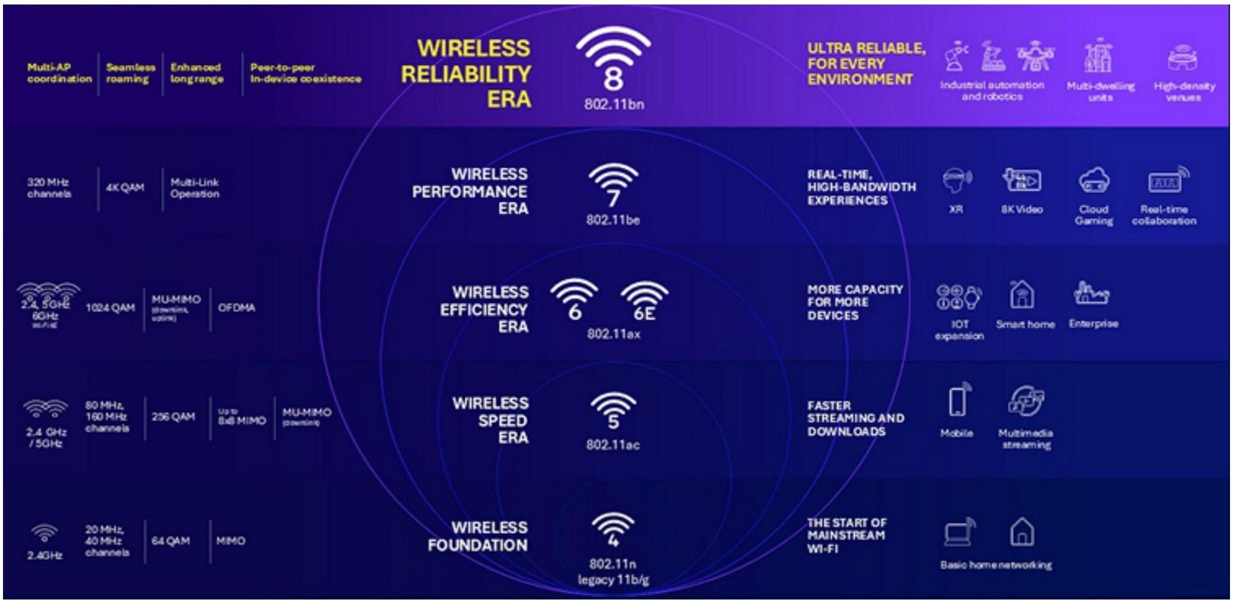
Source: Wireless Broadband Alliance, "Get Ready for Wi-Fi 7"[177]

The WBA has concretely developed[178] on how Wi-Fi 7 features support demanding applications such as immersive XR/AR/VR, online gaming, video conferencing, industrial IoT (IIoT) and Emergency Preparedness Communications Service (EPCS) priority access.

The IEEE is currently developing the Standard 802.11bn or Wi-Fi 8 that is expected to be released in 2028[179]. Wi-Fi 8 is envisaged to aim at industrial applications offering increased reliability compared to Wi-Fi 7. Initial considerations[180] indicate that it could support data rates of up to 100 Gbps enabling not only advanced XR/AR/VR use cases but critical applications, for instance, in the field of autonomous vehicles or medical technologies. It may also support the development of integrated communications and sensing.

[177] WBA. Get Ready for Wi-Fi 7- Applying New Capabilities to the Key Use Cases (2023)
[178] Ibid.
[179] See https://www.ieee802.org/11/Reports/802.11_Timelines.htm
[180] RCR Wireless News. WI-FI Market Pulse Report. A fundamental shift towards reliability and determinism (2025)

Figure 5 The Evolution of Wi-Fi

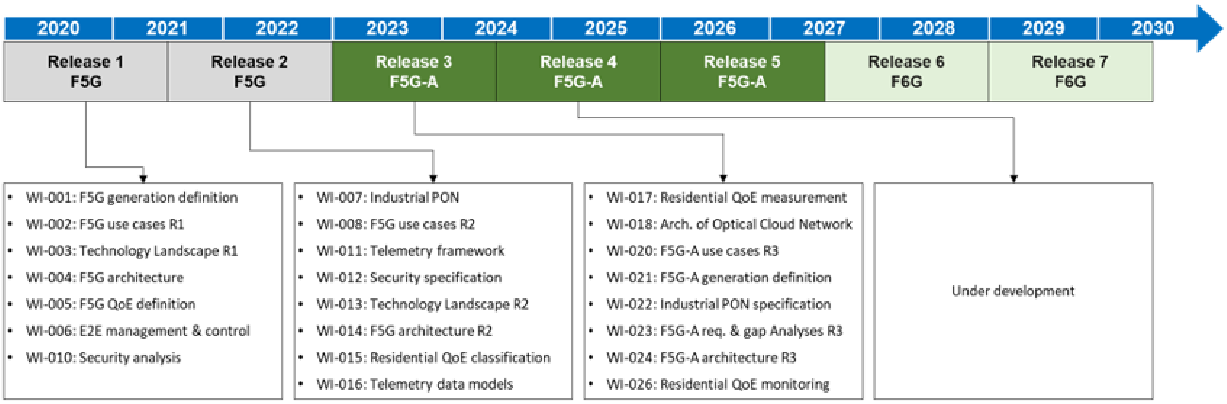


Source: Qualcomm[181]

b. Fixed Networks

In 2023, ETSI published the vision for the 5th Advanced Generation Fixed Networks (F5G-A)[182] that will be developed for 2030 (**Figure 6**) aimed to support the next generation of emerging digital services including the metaverse and Ultra-High Definition (UHD) immersive experience applications.

Figure 6 F5G Release plan



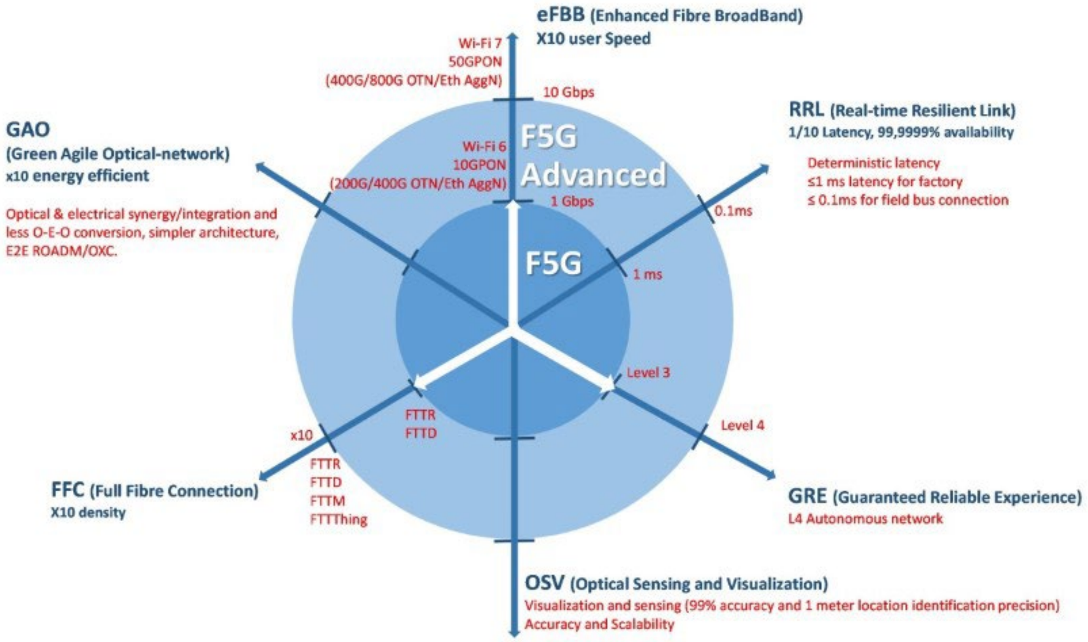
Source: The Evolution of Fixed Networks: ETSI's Role and the Latest F5G-A Release[183]

F5G-A aims at further enhancement of fixed connectivity in six dimensions (**Figure 7)**: i. Enhanced Fixed Broadband (eFBB); ii. Real time Resilience Link (RRL); iii. Guaranteed Reliable

[181] See [Wi-Fi 8: What You Need to Know About the Next Generation of Wireless](#)
[182] See https://www.etsi.org/newsroom/blogs/entry/etsi-released-the-f5g-advanced-generation-definition-promoting-the-evolution-of-f5g
[183] Olivier Ferveur, Chair of ETSI ISG F5G (2025) [The Evolution of Fixed Networks: ETSI's Role and the Latest F5G-A Release](#).

Experience (GRE); iv. Optical Sensing and Visualization (OSV); v. Full-Fibre Connection (FFC) and vi. Green Agile Optical network (GAO).

Figure 7 - Six dimensions of F5G Advanced with enabling technologies characteristics



Source: "F5G Advanced Generation Definition" [ETSI GR F5G 021]

Networks today are migrating to XG(S)-PON delivering 1Gbps connectivity. F5G-A is based in further upgrades to 50G-PON aiming to provide symmetric 10 Gbps.

Table 12 - Fixed network generations

FIXED NETWORK GENERATION	F4G	F5G	F5G-A
GENERATION REFERENCE	UltraFast BB	Gigabit BB	MultiGigabit BB
DL BANDWIDTH/USER	100-1000 Mbps	1-5 Gbps	5-25 Gbps
UL BANDWIDTH/USER	50-500 Mbps	1-5 Gbps	5-25 Gbps
REFERENCE SERVICES	UHD 4K Video	VR Video Cloud Gaming Smart City	Extended reality Metaverse Digital twins Industrial optical network
REFERENCE ARCHITECTURE	FTTH/FTTdp	FTTH/FTTR	FTTR/FTTM/FTTT
ACCESS NETWORK	GPON/G.Fast	10GPON	50GPON
TECHNICAL SPECIFICATION REFERENCE	G.984.x G.9701	G.987.x (XG-PON) G.9807.x (XGS-PON)	G.9804.x

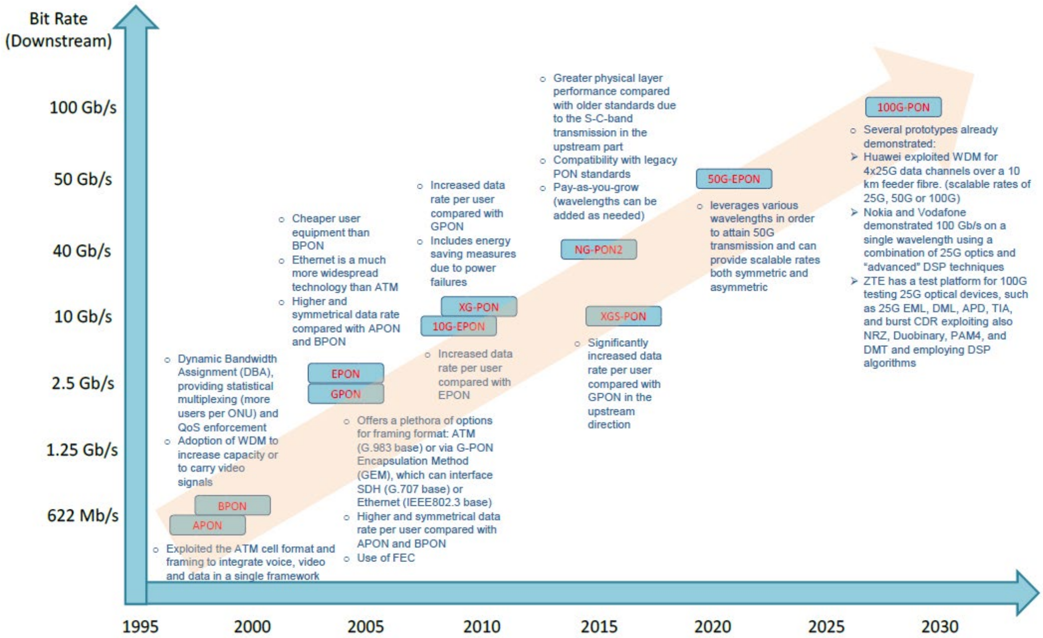
ON-PREMISE NETWORK	FE/GE+Wi-Fi4/Wi-Fi5	GE/10G 2.5 Gbps FTTR (G.FIN) Wi-Fi6 (802.11.ax)	10 Gbps FTTR (G.FIN) Wi-Fi7 (802.11be)

Source: adapted from "F5G Advanced Generation Definition" [ETSI GR F5G 021]

A way to benefit further for fibre developments and its enhanced capabilities is increasing network densification and extending its deployment closer to the user or the devices (FFC in **Figure 7**). The most extensive residential current fibre network deployments locate the termination point at the home of the user (FTTH – Fiber to the home), those are proposed to evolve towards Fiber to the Room (FTTR) solutions. Other models of deployment can adapt to business users and specific needs. This is the case of Fiber to the Machine (FTTM, introducing features for industrial environments), Fiber to the device or to the thing, etc.

Early exchanges for F6G[184] have already started further developing on the proposition of convergence of fixed/wireless communication, computing and sensing into a single technological continuum. Such vision foresees the evolution towards 100GPON standard as shown in **Figure 8.**

Figure 8 - Evolution of downstream bit rate for various PON standards



Source: A Vision of 6th Generation of Fixed Networks (F6G): Challenges and Proposed Directions

[184] Uzunidis, Dimitris & Moschopoulos, Konstantinos & Papapavlou, Charalampos & Paximadis, Konstantinos & Marom, Dan & Nazarathy, Moshe & Munoz, Raul & Tomkos, Ioannis. (2023). A Vision of 6th Generation of Fixed Networks (F6G): Challenges and Proposed Directions.

Some European providers have announced the upgrade of their cable networks to DOCSIS 4.0[185] theoretically permitting up to 10 Gbps DL/ 6 Gbps UL capabilities and future developments have been announced with the objective of reaching 25Gbps[186]. However, these are expected[187] to have more limited impact in Europe than in other regions such as North America due to differences of current cable networks deployment compared to fibre.

Other relevant developments impacting fixed networks (AI orchestration; compute continuum or NF virtualization) are developed under **Chapter 3**.

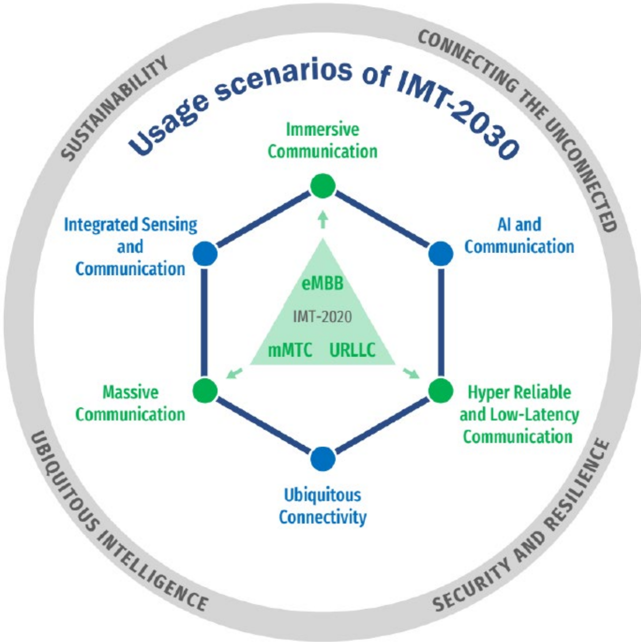
c. 6G Networks

As 5G networks have been conceived as the first cloud-native networks[188], 6G networks are being designed as the first AI-native networks. The 6G/ IMT-2030 specifications developed by the ITU[189] are expected to integrate sensing and AI-related capabilities into communication. As hardware network elements are substituted by software, the application of AI solutions is further enabled facilitating that ECN/S benefit from the extremely fast pacing innovations provided by AI in the last years[190]. Moreover, the ITU proposition includes the aims of offering immersive experiences and blending the physical and virtual world by using a large number of advanced sensors and AI.

The use case scenarios enabled by 6G expand and complement the value proposition of 5G (massive Machine-Type Communications (mMTC), Enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC)) in six new cases: i. Immersive Communication; ii. Hyper Reliable and Low-Latency Communication; iii. Massive Communication; iv. Ubiquitous Connectivity; v. Artificial Intelligence and Communication and vi. Integrated Sensing and Communication. (see **Figure 9**).

[185]See E.g. https://www.commscope.com/press-releases/2022/liberty-global-selects-commscope-as-docsis-4.0-technology-partner
[186]See https://www.prnewswire.com/news-releases/broadcom-charter-communications-and-comcast-to-jointly-develop-unified-docsis-chipsets-capable-of-25gbps-speeds-302258799.html
[187] See https://www.lightreading.com/cable-technology/docsis-4-0-gaining-traction-with-cable-ops-survey
[188] On this matter see, for instance, the BEREC Report on the 5G Ecosystem or the BEREC Report on Cloud and Edge Computing Services
[189] See ITU. M.2160 : Framework and overall objectives of the future development of IMT for 2030 and beyond (2023).
[190] See BEREC Report on the impact of Artificial Intelligence (AI) solutions in the telecommunications sector on regulation

Figure 9 - Usage scenarios of IMT - 2030 (6G)



Source: ITU. M.2160

Some of the estimated targets for research and investigation of IMT-2030 are summarized in **Table 10**.

Table 13 Estimated targets for 6G R&I

ESTIMATED TARGETS FOR RESEARCH AND INVESTIGATION OF IMT-2030	
PEAK DATA RATE	> 20 Gbps
USER EXPERIENCED DATA RATE	> 100 Mbps
LATENCY	0,1 - 1 ms

Source: ITU. M.2160

As in the case of fixed networks, the vision for mobile services is further developed in **Chapter 3** which considers some building blocks that are meant to be common for the development of network communication.

ANNEX V. ACRONYMS

AI – Artificial Intelligence
AI Act – Artificial Intelligence Act
AR – Augmented Reality
ARCEP – Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse
API – Application Programming Interface
BEREC – Body of European Regulators for Electronic Communications
BB – Broadband
BC – Blockchain
CAMARA – Common API framework for mobile networks
CAP – Content and Application Provider
CDN – Content Delivery Network
CSI - Channel State Information
DA – Data Act
DGA – Data Governance Act
DNA – Digital Networks Act
DMA – Digital Markets Act
DSA – Digital Services Act
DT – Deutsche Telekom
EC – European Commission
ECN – Electronic Communications Network
EAA – European Accessibility Act
ECS – Electronic Communications Services
EPCS – Emergency Preparedness Communications Service
ETSI – European Telecommunications Standards Institute
EU – European Union
F5G-A – Fifth Advanced Generation Fixed Networks
FFC – Full-Fibre Connection
GAO – Green Agile Optical network
GDPR – General Data Protection Regulation
GHG – Greenhouse Gas
GRE – Guaranteed Reliable Experience
IIoT – Industrial Internet of Things
IoT – Internet of Things
ISO – International Organization for Standardization
ISP – Internet Service Provider
ITU – International Telecommunication Union
MEC – Multi-access Edge Computing
MR – Mixed Reality
MS – Member States
NaaS – Network as a Service
NEF – Network Exposure Function
NRA – National Regulatory Authority
NFT – Non-Fungible Token
OGC – Open Geospatial Consortium
OSV – Optical Sensing and Visualization
QoE – Quality of Experience
QoS – Quality of Service
RRL – Real Time Resilience Link
SA – Standalone
SDO – Standards Developing Organization
SNS JU – Smart Networks and Services Joint Undertaking
TIP – Telecom Infra Project
TSN – Time-Sensitive Networking
UHD – Ultra-High Definition
URLLC – Ultra-Reliable Low-Latency Communication
V2X – Vehicle-to-Everything
VHCN – Very High Capacity Network
VR – Virtual Reality
VW – Virtual Worlds
W3C – World Wide Web Consortium
WAI – Web Accessibility Initiative
WBA – Wireless Broadband Alliance
XR – Extended Reality