Networks of the future

Prepared for Liberty Global

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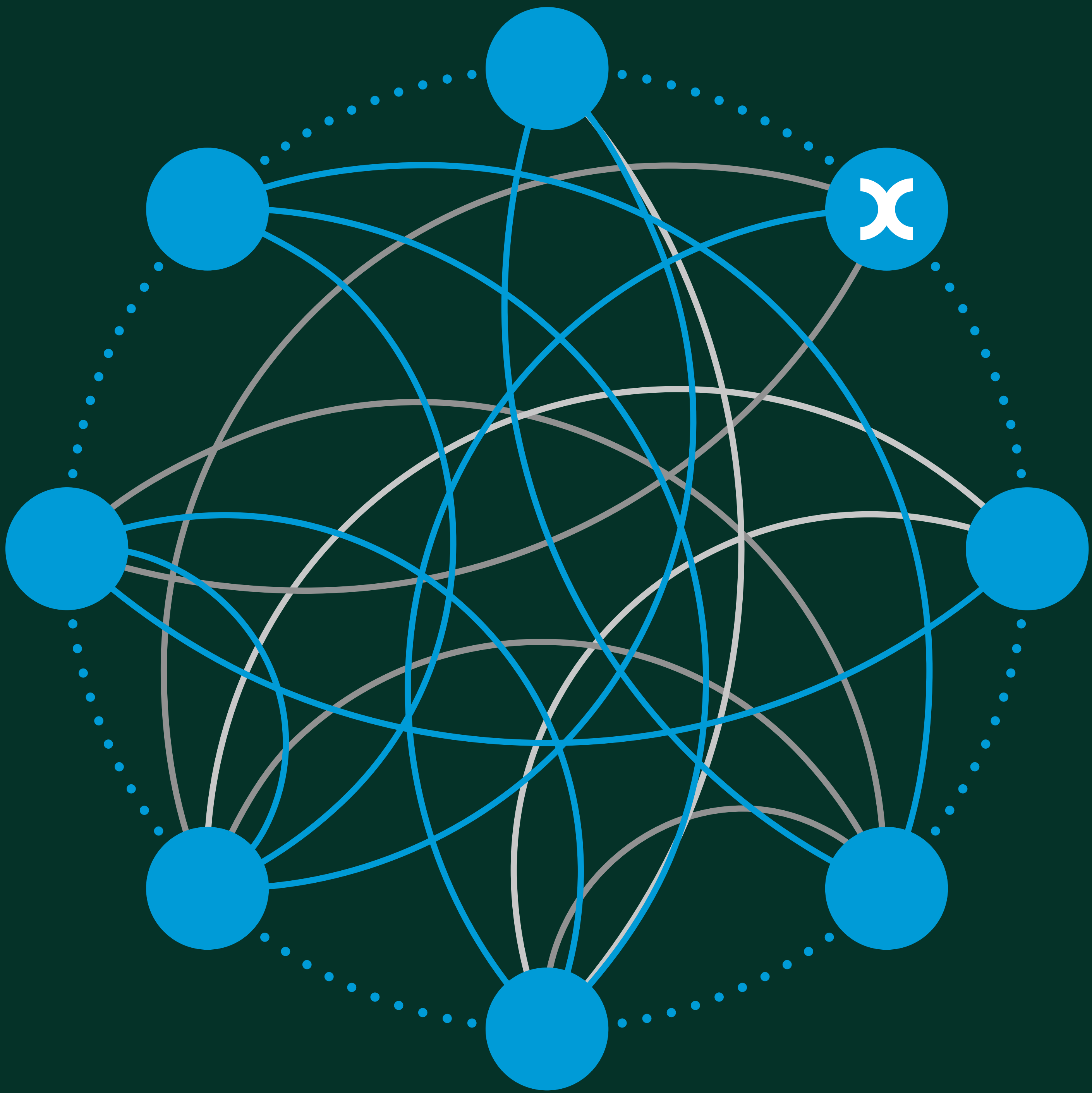

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Executive summary

We have explored the development of the internet and what can be expected from it going forward, given innovative new network technologies. This brief paper is not intended to be comprehensive; instead, it offers a selection of use cases to highlight potential directions of development for the **networks of the future**. It is intended to contribute to an open, evidence-based discussion among all those who help to shape the networks of the future in a dynamic world.

The 'best-effort' internet has come a long way

The public internet has evolved organically due to a number of developments and investments, collaboration between network and content providers, and (as a consequence) increasing demand from business and end-users.

The COVID-19 pandemic has tested the robustness of the current public internet. In general, networks have been able to deal with sudden increases in traffic (and changes in demand patterns) because internet service providers (ISPs) have built their networks to handle peak demand. Networks were able to accommodate many users online at the same time—which, together with strong collaboration between different participants throughout the internet value chain, illustrated how robust these networks are.

However, recent trends in connectivity between actors throughout the internet value chain indicate that demand is changing. In this dynamic space, bandwidth and speed are no longer the only key characteristics; there is increasing demand to improve experiences for end-users by controlling the **quality** of their content. In addition, characteristics such as latency, jitter and security have become more important.

Until now, these improvements have been delivered within the boundaries of the shared medium of the internet through: (i) more interconnection points to have shorter travel routes; (iii) more direct interconnections, such as via private peering; and (iii) bringing the static content closer to the end-user through the deployment of content delivery networks. Other trends demonstrating the increased demand for quality include a rise in the use of content markings, which can help with prioritisation at transit points.

Innovation is driving new opportunities

At the same time, new developments in technology have triggered opportunities for new use cases. The advent of 5G mobile technology and edge computing promise capabilities that can enhance services and use cases across the internet value chain. For example, 5G technology is capable of offering tailored connectivity with guaranteed parameters on latency and capacity by virtually separating the network into slices for specific purposes.[1]

[1] Ericsson (2021), 'Network slicing: A go-to-market guide to capture the high revenue potential'.

Likewise, edge computing means that data could be stored and analysed closer to end-users or data generators instead of in a centralised, distant data centre.[2] As the information travels shorter distances, it would further reduce latency and increase security because it reduces the chance of malicious interception.

These innovations have spurred a range of ideas about how they could be used. We have delved into four use cases that could use these technologies:

- autonomous vehicles;
- product quality control and digital twins;
- boosts to online gaming;
- metaverses.

These use cases are illustrative, not limitative, and are meant to describe the potential of the networks of the future. Together, they show that the networks of the future must be ready to provide low latency, higher throughput, guaranteed availability, and security as this will open the world to a wide range of applications and services that create value for consumers (including businesses).

Networks of the future need new models of collaboration and differentiation

The development of network technologies and the use cases we explored reveal two key implications for the networks of the future.

First, the participants in the internet value chain should be able to explore new models of collaboration, as these might unlock new propositions that create value for everyone, from businesses to end-users. For example, ISPs might adopt a multi-sided business model whereby they provide their network as a service (NaaS) to application providers, when needed, to deliver higher-quality services. This model of collaboration could incentivise the take-up of innovations when uncertainty over demand means that participants in the value chain are reluctant to make the necessary investment for a use case.

Second, to enable these types of use cases, network services need a new model that offer differentiation in quality. Being able to request a tailored network that matches the specific needs of an application will allow the development and provision of innovative services that benefit all actors in the value chain, including consumers, who will be given more choice and access to innovations. Without quality differentiation some use cases might never become reality.

In this context, we observe that the existing regulatory frameworks in the EU can be seen to be ambiguous, and if they are interpreted in a narrow way this could potentially hamper some of the innovations we explore in this paper. We consider that regulators should adopt a principles- and evidence-based approach that continues to protect business users and end-users while allowing the flexibility needed to explore and implement new business models that bring benefits across the internet value chain.

[2] Ericsson (2022), 'Edge computing infrastructure and beyond'.

1 The evolution of the internet

Before looking ahead, it is useful to reflect on where we are today and how we arrived here. This section reflects on the development of the public or 'best-effort' internet until now. It highlights the collaboration that has taken place between various stakeholders (see Appendix A1) and the relevance of content in driving the continuous growth in consumption of data and the organic evolution of the internet.

1.1 The evolution of internet networks

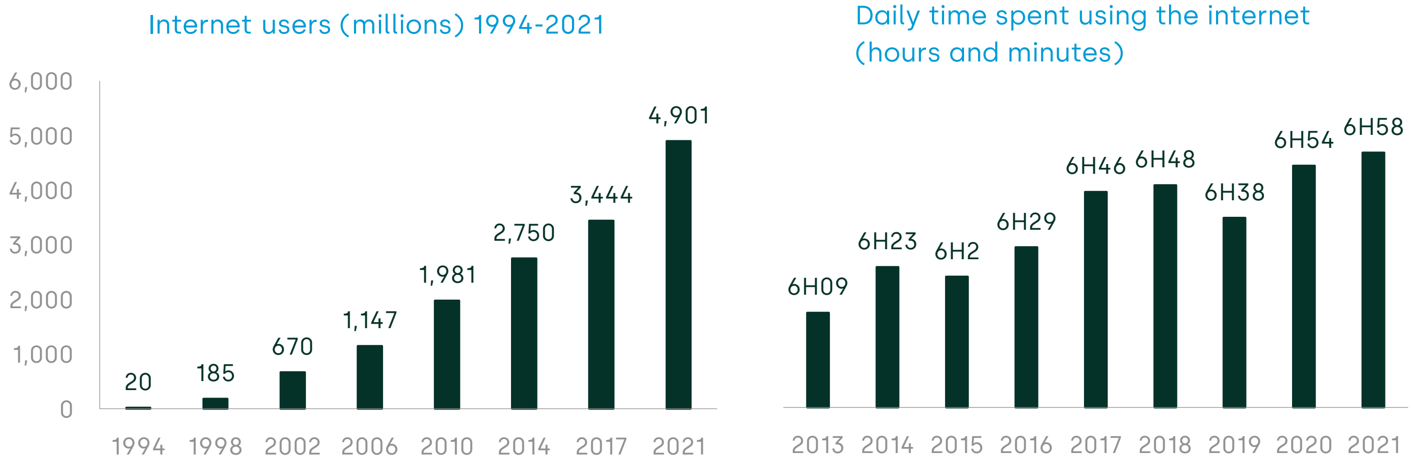
Since its creation in the late 1960s, the internet has grown continuously to keep up with an increasing number of users joining the network (reaching 5bn users globally in 2021),[3] an increasing number of activities moving from offline to online (e.g. entertainment, work, and medicine), and the development of novel applications (e.g. online gaming).[4]

This consistent increase in users over recent decades has occurred in parallel with an increase in both average time spent on the internet (6 hours and 58 minutes in 2021)[5] and volume of traffic per user (see Figure 1.1).[6] These trends have resulted from an increase in the number of devices used to connect to the internet—due to increased smartphone penetration, the spread of wearable devices, and the rise of internet of things (IoT) devices.[7]

Because of the consequent shift from offline to online activities, today's society and economy rely heavily on the internet. More and more people now depend on it for work, education, social interaction, and entertainment, and engage with online activities such as video streaming, social networking, web browsing, and online gaming.[8]

[3] ITU (2022), 'Global Connectivity Report 2022'.
[4] The observed growth in internet use has concerned also business users. Indeed, over time business connectivity has increased—in 2021 93% of businesses across OECD countries had a broadband connection. See Organisation for Economic Co-operation and Development, Broadband Portal.
[5] The average time spent on the internet is calculated as the average time that internet users aged 16 to 64 spent using the internet each day on any device in 2021. See Kemp, S. (2022), 'Digital 2022: Global Overview Report', *Datareportal*, 26 January.
[6] Between 2019 and 2021 the data traffic per connection in Europe has increased by 53% for fixed and by 90% for mobile connections, even though the growth rate for the latter is now decelerating. See GSM Association (2022), 'The Internet Value Chain 2022', 15 May; European Telecommunications Network Operators' Association (2022), 'State of Digital Communications 2022'; Mohr, G., Pankert, G., Khan, S., Meige, A., Goddard, M., Tazi, A. and Kerr, M. (2022), 'The Metaverse: what's in it for telcos?', Arthur D. Little, October; Tefficient (2023), 'Further slowdown in data usage growth causes positive ARPU development to soften', Industry Analysis #3 2022, 9 January.
[7] Statista (2023), 'Global smartphone penetration rate as share of population from 2016 to 2021'; Government Office for Science (2023), 'Wireless 2030: A scenarios analysis of public service demand for wireless connectivity in 2030', January; Statista (2022), 'Internet of Things (IoT) and non-IoT active device connections worldwide from 2010 to 2025'; European Telecommunications Network Operators' Association (2022), op. cit.
[8] Axon Partners Group for ETNO (2022), 'Europe's internet ecosystem: socioeconomic benefits of a fairer balance between tech giants and telecom operators', henceforth referred to as Axon (2022).

Figure 1.1 Number of internet users and the average time they spend online



Source: Oxera, based on ITU (2022) and Datareportal (2022).

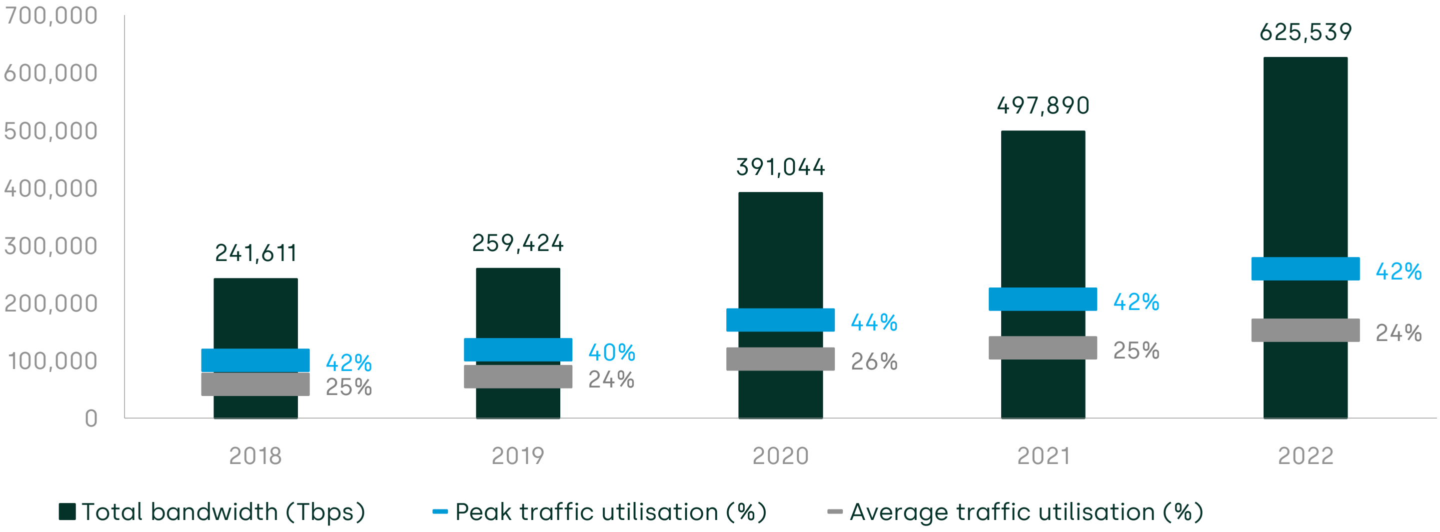
The evolution of user habits and the subsequent increase in demand for data have been simultaneously the cause and the consequence of the development of internet networks. Technological advancements such as moving from DSL to fibre, and from 2G to 3G, 4G, and 5G, mean that the quality of fixed and mobile networks have significantly improved over time, especially in terms of the bandwidth they offer.

At a global level, average internet speeds have doubled between 2015 and 2021, reaching an average speed of more than 120Mbps,[9] with many countries now investing in fixed broadband connections offering speeds of 1Gbps.

Total international bandwidth has reached 997Tbps in 2022 — almost doubled since 2020.[10] Between 2018 and 2022, global bandwidth capacity has grown at a CAGR of 29%, which mirrors the growth of average and peak international internet traffic at a CAGR of 30%.[11] In Europe, bandwidth capacity has grown at a CAGR of 27% over the same period, reaching 626Tbps in 2022.[12] In the same year, average and peak traffic were respectively 153Tbps and 260Tbps, which correspond to an average and a peak utilisation of 24% and 42% (see Figure 1.2).[13]

[9] European Telecommunications Network Operators' Association (2022), op. cit.
[10] Telegeography (2022), 'Executive Summary: Global Internet Research Service'.
[11] ibid.
[12] ibid.
[13] ibid.

Figure 1.2 European internet bandwidth, average traffic, peak traffic and utilisation between 2018-2022



Source: Oxera, based on Telegeography (2022).

One of the main drivers of network growth has been the increase in the magnitude and frequency of traffic peaks, due to the spread of high-demand activities such as the livestreaming of sport events or simultaneous downloads of popular games by many users.[14] While networks are designed to accommodate busy hours that have regular patterns, it is rare events that exert pressure on networks and push ISPs to adapt them in order to accommodate the increase in demand.[15]

European networks have largely avoided congestion during the COVID-19 pandemic

In this respect, the COVID-19 pandemic has put the limits of the existing networks, CDNs and other elements of the internet value chain to the test. In Europe, networks have shown that they could handle the increase and change in traffic, while largely avoiding congestion.[16, 17]

Nonetheless, in order to keep meeting growing user demand, the internet is expected to further develop in the future, while new technological advancements will continue to expand the networks' capabilities.

[14] Euro-IX reports that the average aggregated peak traffic per year within Euro-IX membership has almost doubled between 2016 and 2020, when it reached 45,325 Gbps. See Euro-IX (2020) 'Internet Exchange Points 2020 Report'.
[15] Ofcom (2022), 'Consultation: Net neutrality review'.
[16] Body of European Regulators for Electronic Communications (2021), 'Report on COVID-19 crisis – lessons learned regarding communications networks and services for a resilient society'; Authority for Consumers & Markets (2021), 'COVID-19 pandemic does not cause problems for open internet'.
[17] We note that the management of congestion has also been due to the enhanced collaboration among different actors. For instance, major video streaming services (including YouTube and Netflix) downgrading their streaming to counter potential network congestion. See WIK-Consult (2022), 'Competitive conditions on transit and peering markets: Implications for European digital sovereignty', 28 February.

1.2 Shifting the focus from throughput to quality

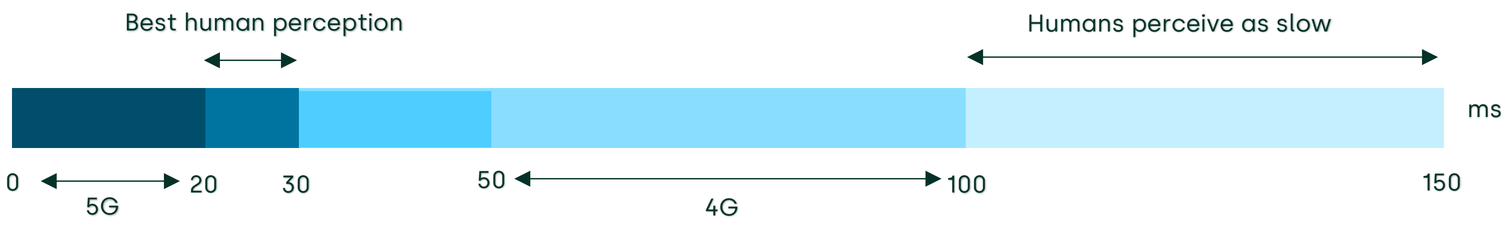
While the public internet appears to be working well for now, a recent trend in how some participants in the value chain interact indicates there is demand for more end-to-end (E2E) quality.

In particular, in recent years, there has been a shift towards more direct interconnections, at more locations and closer to end-users, to improve latency—the time it takes for a data packet to travel from one designated point to another.[18]

Latency on 4G is in the range of 50-100ms

While humans might not be able to detect latency improvements below 20–30ms,[19] and consider latency in the range of 100–150ms to feel like 'the internet is slow',[20] low latency is of particular importance for certain applications, such as live video, online gaming, connected vehicles or robots in manufacturing. Currently, the level of latency that can be delivered by the public internet is highly variable: some research indicates that between 2014 and 2017, average fixed latency in Central and Eastern Europe decreased from an average of 47ms to 33ms, but it can reach 1ms on the latest PON fibre networks.[21] The latency on 4G seems to be in the range of 50–100ms (see Figure 1.3).[22]

Figure 1.3 Latency ranges on mobile networks



Source: Oxera.

The main factors affecting latency include the medium that data is travelling through (fibre vs copper), speed (low upload and download speeds are strongly correlated with high latency), throughput (low throughput is also associated with high latency), distance travelled (e.g. for every 100 miles of fibreoptic cable, approximately 1ms of latency is added), and network management of traffic (e.g. efficiency of routers and software).[23]

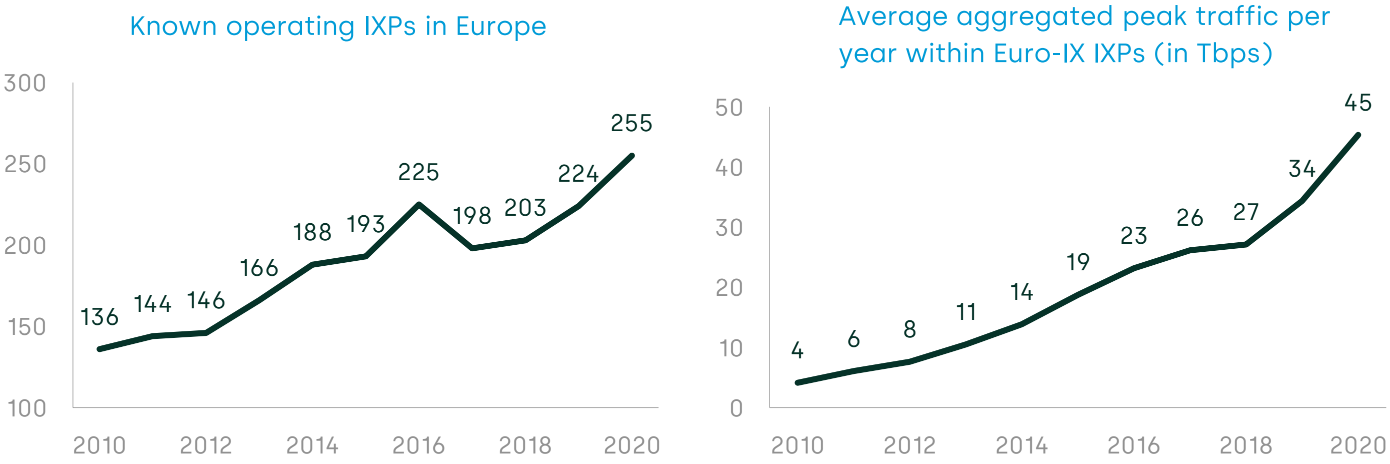
Below, we describe three trends that have characterised the recent evolution of internet networks, leading to lower latency and reduced jitter (i.e. the variation in latency).

First, the need for shorter routes to preserve quality has led to an increasing number of IP interconnection providers reducing the

[18] WIK-Consult (2022), op. cit.
[19] Ericsson Blog (2022), 'Who cares about latency in 5G?', 16 August.
[20] Scaleway Blog (2022), 'Network Latency: how latency, bandwidth & packet drops impact your speed', 15 May.
[21] Nokia (2022), 'Fiber for Everything: A new era where fiber PON infrastructure connects everything and everybody'.
[22] Ericsson Blog (2022), op. cit.
[23] Cambridge Management Consulting (2021), 'Achieving ultra-reliable networks in 2022: the challenge of delivering 5G and low latency', 19 October.

number of hops that data needs to pass. This implies more interconnections points at more locations, to enable end-to-end traffic to take more direct routes. Over the past decade, the number of operational internet exchange points (IXPs) in Europe has increased by 87.5%, from 136 in 2010 to 255 in 2020.[24] Moreover, the number of connected networks at each IXP has also increased. All the while, average aggregated peak traffic at IXPs has increased by a factor of 10 between 2010 and 2020 (see Figure 1.4).[25]

Figure 1.4 IP exchanges in Europe and their peak traffic between 2010 and 2020



Source: Oxera, based on Euro-IX (2020).

While smaller providers continue to use transit, there has been a generalised shift from transit to peering

Second, while smaller providers continue to use transit, there has been a generalised shift from transit to peering—the direct interconnection between separate networks. Moreover, peering preferences have shifted from the use of IXPs for multilateral public peering to bilateral private peering through direct interconnection, either at data centres or within the network.[26] In general, peering paths have a higher quality than transit paths, both in terms of improved latency (due to shorter path length) and fewer queuing delays.[27]

Third, over the past few years, large CAPs have made substantial investments in digital infrastructure (including hosting and transport),[28] and have started to bring their content closer to end-users through the deployment of their own CDNs or the use of third-party CDNs on the network.

CDNs have become very important for the delivery of content over the internet.[29] For instance, one of the largest CDNs, Akamai, is estimated

[24] Euro-IX (2020), op. cit.
[25] ibid.
[26] WIK-Consult (2022), op. cit.
[27] See WIK-Consult (2022), op. cit.; Ahmed, A., Shafiq, Z., Bedi, H. and Khakpour, A. (2017), 'Peering vs. Transit: Performance Comparison of Peering and Transit Interconnections'. IEEE 25th International Conference on Network Protocols (ICNP), IEEE.
[28] WIK-Consult (2022), op. cit.; Analysys Mason (2022), 'The Impact of Tech Companies' Network Investment on the Economics of Broadband ISPs', 12 October; Analysys Mason (2022), 'Netflix's Open Connect program and codec optimisation helped ISPs save over USD1 billion globally in 2021', 14 July.
[29] Ofcom reports that, in the UK, between 13% and 25% of total traffic during busy hours is delivered by only two CDNs. See Ofcom (2022), op. cit.

The CDN market is estimated to grow at a CAGR of over 29%

to deliver over 21Tbps—that is, 15–30% of all daily internet traffic.[30] Across all Europe, the CDN market is estimated to grow at a CAGR of over 29% to reach $16.79bn by 2025.[31] Studies conducted by the Dutch Authority for Consumers and Markets (ACM) and WIK-Consult—the German Scientific Institute for Infrastructure and Communication Services—confirm this pattern of continuous growth in different countries.[32] In France, the French Regulatory Authority for Electronic Communications and Postal services (ARCEP) reports that on-net CDN traffic has almost doubled between 2019 and 2020 (+82%), representing 21% of total traffic in 2020. In the same year, peering and transit represented 41% and 83% respectively.[33]

Overall, the use of private peering, on-net CDNs and spatially distributed servers has favoured the regionalisation of transport and allowed a more efficient delivery of content, which is less likely to encounter congestion, delay, or data loss and data corruption, leading to a better experience.

These developments are bringing the quality of the general internet closer to the quality of business internet. What all these (private peering, on-net CDNs and business internet) have in common is that they move away from traditional connectivity model of 'packet-switched networking', and towards a 'circuit-switched networking' model.

There currently exists a trade-off between network efficiency and quality guarantees

By assigning fixed resources on a (physical) medium to a particular user (e.g. by logical separation from other services, or within a service), 'circuit-switched networking' ensures guaranteed bandwidth and consistency across other quality parameters, including latency and security. However, this is only possible at the expense of the efficiencies deriving from the resource-pooling in the 'packet-switched networking' model. This shows that there is currently already a trade-off between network efficiency and quality guarantees.

In parallel, on transit, a new practice—'Differentiated Services Code Point (DSCP)'—uses markings to indicate the recommended level of differentiation for different traffic flows when they are en route (e.g. low-priority data, high-throughput data, low-latency data, real-time interactive, broadcast video, etc.). Though not widespread,[34] the use of markings suggests that there is increasing demand for prioritised traffic flows that take into account other network requirements besides speed.

[30] Akamai (2012), 'Traffic Engineering for CDNs'.
[31] ResearchAndMarkets.com (2021), 'Europe Content Delivery Network Market Report 2020-2025: Video CDN Vs. Non-Video CDN - Competition Forecast & Opportunities - ResearchAndMarkets.com', 12 May.
[32] See Authority for Consumers & Markets (2021), op. cit.; WIK-Consult (2022), op. cit.
[33] ARCEP (2021), 'The state of the internet in France', 2021 report.
[34] Information received from Liberty Global indicates that DSCP-markings are used for approximately 4% of peak traffic.

There is increased demand for end-to-end quality

Overall, the trends illustrated above have supported the organic consolidation of a much more capable internet in terms of processing, transmission, and the capability to adapt dynamically. However, they also suggest that there is increased demand for end-to-end quality of the information that travels on the internet, and that could be at the edge of what the shared medium can provide.

1.3 Recent technological developments

Opportunely, new technological developments have started to enter the market. In particular, the advent of 5G mobile technology and edge computing have the potential to enhance the activity of many actors in the internet value chain.

5G could deliver ultra-low latency and higher data rates

5G is the fifth generation of mobile networks, and it is the next step in the evolution of mobile communications. It uses multiple frequency ranges, some different from previous generations of mobile networks, which enables more data to be transmitted over the airwaves. The technology is still evolving at present. However, once it matures and Standalone 5G (5G SA) is deployed through the pairing of 5G radios with a cloud-native 5G core network, it could deliver ultra-low latency (less than 20ms,[35] and possibly even lower than 1ms)[36] and higher data rates.[37]

In addition, because 5G has Service Based Architecture (SBA), which virtualizes network functions altogether, the 5G core network could provide the ability to subdivide or slice the network to allow multiple virtual networks to be created on top of a common physical infrastructure, each with its own unique characteristics and resources.[38]

Edge computing technology brings computation and data storage closer to the devices that generate and consume the data

Moreover, edge computing technology brings computation and data storage closer to the devices that generate and consume the data due to their distributed computing architecture.[39] This has the potential to contribute to reduced latency, reliability and security (due to shorter distances over which data needs to travel), as well as reduced costs and scalability when deployed. At the same time, it will contribute to the trend of regionalisation of networks, as data will travel fewer distances. This regionalisation of networks versus the original world wide web is another example of how networks are evolving.

These latest advances in technology have triggered opportunities for new use cases. In the next section, we showcase four use cases to illustrate the potential of new network capabilities.

[35] Ericsson Blog (2022), op. cit.
[36] McKinsey & Company (2022), 'The future of automotive computing: Cloud and edge', 6 October.
[37] Ericsson Blog (2019), 'Non-standalone and Standalone: two standards-based paths to 5G', 11 July.
[38] Ericsson (2021), 'Network slicing: A go-to-market guide to capture the high revenue potential'.
[39] Ericsson (2022), 'Edge computing infrastructure and beyond: the 5 key factors for better edge choices', 31 May.

2 New use cases

The public internet has been evolving and adapting well to the demand it has encountered until now. With increased reliance on the internet infrastructure and advances in technology as described in section 1, new use cases are starting to emerge.

There is much uncertainty about what form these use cases will ultimately take and if and how they will materialise over time. However, some industry experts point to the fact that a number of applications on the horizon have a set of network requirements for E2E quality (e.g. low latency and jitter, higher throughput, increased security and guaranteed availability) that cannot be delivered by the current public internet.[40]

Below, we highlight four use cases that emphasise why a higher quality of service might be required from the networks of the future. These use cases are only meant to illustrate the potential of new network capabilities, rather than covering their full potential. Table 2.1. summarises the use cases that we selected.

Table 2.1 Summary of selected new use cases

Use case	Highlight	Key quality parameters
Autonomous vehicles	Real-time operation of remote devices	Low latency and jitter, security
Production and digital twins	Real-time optimisation of production processes	Security, low latency, security
Metaverses	Wide-scale adoption of VR/AR devices and novel applications	High bandwidth, low latency, security
Cloud gaming boosts	Targeted improvement of the user experience through network performance	High Bandwidth, low latency

Source: Oxera.

2.1 Autonomous vehicles

What is the need?

Connected and autonomous vehicles are expected to bring radical changes in transport logistics and people's mobility while improving road safety.[41] For example, the European Commission highlights the importance of technology in improving road safety in the new EU Vehicle General Safety Regulation, which is seen as an important step towards the adoption of automated and fully driverless vehicles in the EU.[42]

As the automotive industry is moving towards the adoption of a model of connected and automated vehicles on public roads, the prevention

[40] Ericsson (2021), 'Network slicing: the top 10 most profitable industries', 7 June.
[41] Autonomous vehicles also have applications in other industries. For instance, Caterpillar is using autonomous trucks in mining. See PRNewswire (2023), 'Caterpillar to Showcase Technology, Autonomy and Sustainability at CES® 2023', 5 January.
[42] European Commission (2022), 'New rules to improve road safety and enable fully driverless vehicles in the EU', press release, 6 July; European Parliament (2021), 'EU Road Safety Policy Framework 2021-2030 – Recommendations on next steps towards "Vision Zero"'.

of accidents is indeed an important challenge.[43] Autonomous vehicles are expected to use information from onboard sensors and systems to understand their global position and local environment, enabling them to operate with little or no human input. Safety can be improved with real-time sharing of data and information between different participants in traffic, ensuring different levels of communication, including inter- and intra-vehicle communication as well as communication between the vehicle and the network.[44]

What do autonomous vehicles need?

A number of recent studies show that the adoption of autonomous vehicles will need a network connection with different characteristics, as their features will impose different quality requirements.[45] In particular, a well-functioning autonomous vehicle is expected to require around 10Mbps throughput and 1ms latency.[46]

First, ultra-low latency is needed for lag-free transmission of data and commands. This is considered particularly important given the amount of data that is transmitted (e.g. GPS location, engine status, acceleration and braking) and received (e.g. weather or traffic alerts, location of other vehicles, road signs) by autonomous vehicles.

All this data needs to be transmitted in real time: route planning, responses and decisions need to be immediate, as performance issues can jeopardise the safety of other drivers and pedestrians on the streets.

Similarly, features such as smart traffic management systems or situational awareness systems require reliability and guaranteed availability of the connection, as lost connections could have severely negative consequences.

Indeed, autonomous vehicle operators must always have control of the situation and the ability to monitor and adjust their vehicle's behaviour in case of unforeseen obstacles, perform controlled emergency stops, and contact the passengers of the vehicle. Therefore, to guarantee safety, autonomous vehicles should always remain connected to the network.[47]

[43] See, European Commission (2020), 'Ethics of connected and automated vehicles: Recommendations on road safety, privacy, fairness, explainability and responsibility', 17 September; Shetty, A. et al. (2021), 'Safety challenges for autonomous vehicles in the absence of connectivity', *Transportation Research Part C: Emerging Technologies*, **128**:103133, July; Koopman, P. and Wagner, M. (2017), Autonomous Vehicle Safety: An Interdisciplinary Challenge, *IEEE Intelligent Transportation Systems Magazine*, **9**:1, pp. 90–96.
[44] Government Office for Science (2023), op. cit.
[45] See, for instance, Hakak, S. et al. (2023), Autonomous Vehicles in 5G and Beyond: A Survey, *Vehicular Communications*, **39**:100511; Ahangar M.N. et al. (2021), 'A Survey of Autonomous Vehicles: Enabling Communication Technologies and Challenges', *Sensors*, **21**:3, 706; TE Connectivity (2018), '6 Key Connectivity Requirements of Autonomous Driving', *IEEE Spectrum*, 4 October.
[46] Keysight (2018), 'Test Considerations for 5G New Radio', White Papers.
[47] Ericsson (2021), 'Five things you need to know about Connected Autonomous Vehicles', 15 November.

For the same reason, connection security is essential to guarantee that only authorised people or service providers can access vehicle controls.

Finally, the volume of data that autonomous vehicles will generate, process, transmit and receive are predicted to be large. While the widespread uptake of autonomous vehicles by 2030 is unlikely, even their limited adoption is expected to lead to significant data demands (above 40Tbps, according to UK estimates) in order to guarantee safety.[48] Intel estimates that once adopted, each autonomous vehicle may generate more than 4TB of data per day.[49]

In addition, the co-existence of both autonomous and legacy vehicles would likely require extensive use of machine learning algorithms while on the go, which existing infrastructure is currently incapable of handling on a large scale.[50] This means that autonomous vehicles will require a fast and reliable connection that allows them to process data at the edge of the network, once the onboard capabilities of vehicles have been exceeded.[51]

What are the potential benefits?

The adoption of fully autonomous vehicles is seen as a way to improve road safety and drastically reduce accidents in the future, with consequent benefits related to value of life, insurance premiums and compensation costs.[52]

In addition, a number of other monetary and non-monetary benefits could arise from the uptake of autonomous driving. These include higher traffic efficiency, increased comfort and convenience for passengers, improved access to the disabled and people with reduced mobility, and cost savings for fleet operators due to lower staff costs and efficiencies in fuel from optimisation when these vehicles are used for transport.

Finally, it is expected that these vehicles will operate based on clean energy, so carbon and greenhouse gas emissions are also expected to be significantly reduced.[53]

2.2 Product quality control and digital twins

What is the need?

In recent years, manufacturing has faced a series of challenges, as producers have had to adjust to the disruptions in supply and demand

[48] Government Office for Science (2023), op. cit.
[49] Data Center Frontier (2017), 'Autonomous Cars Could Drive a Deluge of Data Center Demand', 25 May.
[50] Jameel, F., Chang, Z., Huang, J. and Ristaniemi, T. (2019), 'Internet of Autonomous Vehicles: Architecture, Features, and Socio-Technological Challenges', *IEEE Wireless Communications*, **26**:4, pp. 21–29.
[51] Making this a reality in the automotive sector, as in others, will rely on appropriate connectivity. The European Commission recognises this in its European Strategy for Data—the EU's plan to maximise the benefits of data for economic growth, competitiveness, job creation, and well-being.
[52] Human error is estimated to play a role in 95% of accidents. See: European Commission (2016), Saving Lives: Boosting Car Safety in the EU, COM/2016/0787.
[53] Ericsson (2021), 'Network slicing: the top 10 most profitable industries', 7 June.

caused by the COVID-19 pandemic, as well as to changing consumer behaviours.

Two trends have emerged in particular: (i) consumers are increasingly focused on transparency and environmental sustainability; and (ii) consumers tend to buy more products online. This has forced manufacturers to respond quickly, by including new types of products, sustainable packaging, and new digital channels. All this while ensuring product safety, by performing regular testing and tracing raw materials, ingredients, or components.

In light of these challenges, agility and adaptation have become essential. In this respect, manufacturing can be significantly improved and optimised with the adoption of smart technologies and the use of digital twins—a software-based replica of the manufacturing plant and its assets that can aid with quality inspection, optimisation and other purposes. These innovations can allow real-time monitoring (through video usage and sensors) and control of machinery, streaming of complex data, monitoring of inputs and outputs, and layout planning without affecting production line.[54]

What does it need?

The digital transformation of manufacturing facilities is predicted to require high-quality network connection characterised by high throughput, low latency and high security.[55]

It is expected that smart manufacturing will adopt horizontal and vertical system integration, advanced robotics, cloud services, industrial IoT devices, simulation software, AR, AI and other technologies to enable extensive automation and flexibility on the production floor.[56] Together, they will require high throughput connections to send and receive high quantities of video data to be processed in real-time.

Low latency will be needed to have real-time data synchronisation and control, for instance to connect remote workers through AR devices inside and outside the factory, or for real-time monitoring of inputs and processes. Low latency is also crucial to provide seamless transition and exchange between the digital twin environment and the physical space, allowing changes made in one dimension to be immediately reflected in the other. It is estimated that most applications of smart manufacturing technologies will require a latency lower than 10ms.[57]

Finally, an additional requirement for digital twins and smart manufacturing is high security, to avoid breaches and interreferences.

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[54] Accelerating the twin transition is among the aims of the European Industrial Strategy laid out in 2020, and updated in 2021. See European Commission (2020), 'European industrial strategy'. See also European Commission (2021), 'Updating the 2020 Industrial Strategy: towards a stronger Single Market for Europe's recovery'.
[55] Ericsson (2021), op. cit.
[56] ibid. See also Industry Week (2015), 'On the Journey to a Smart Manufacturing Revolution', 30 December.
[57] Spirent (2022), 'Cutting Through the Edge Computing Hype'.

It is paramount that data cannot be intercepted or modified by unauthorised users while being transmitted over the network.

What are the potential benefits?

Overall, guaranteed quality of service can enable the effective digitalisation of manufacturing through the use of smart technologies and digital twins, to the benefit of both producers and consumers. Likely outcomes include improved input and output performance, better quality control management, asset optimisation, enhanced demand forecasting and preventative maintenance capabilities.[58]

This can drive higher productivity, machine life, better utilisation of resources, energy and floorspace, and can also reduce costs related to maintenance, operator labour, service trips and quality inspections. For instance, the use of digital twins can help reduce costs through preventive maintenance, by predicting failures before they affect or damage the products.

Moreover, the use of digital twins could enable manufacturers to craft personalised products for their customers and improve overall product quality and choice. This can be directly beneficial to consumers and also translates into improved manufacturing business profitability.

Additional potential benefits resulting from the manufacturing digitalisation include reduced CO2 impact from service expert travel, reduced energy consumption through the adoption of technologies that allow a more effective control of the energy used, and overall better ergonomic environment.[59]

The described advancements are particularly important in relation to manufacturing, as the smart factory market size is estimated to grow from $165bn in 2019 to $250bn by 2024.[60] According to a study conducted in 2019, the vast majority of US manufacturers expect smart manufacturing to be the main driver of competitiveness and to transform the way products are made in the next few years.[61]

This phenomenon, which has been defined as the fourth industrial revolution, or Industry 4.0, has gained growing importance in Europe.[62] The European Commission has recognised the impact that digitalisation and robotics can have on Europe's capacity to maintain and expand a competitive manufacturing sector covering millions of related jobs.[63]

Moreover, the European Commission has also emphasised that robotics and similar advanced technologies can help offer new

[58] Mashaly, M. (2021), 'Connecting the Twins: A Review on Digital Twin Technology & its Networking Requirements', *Procedia Computer Science*, **184**, pp. 229–305.
[59] The Manufacturer (2022), 'How smart manufacturing and AI can benefit the environment', 30 June.
[60] Statista (2021), 'Global size of the smart factory market in 2019 and 2024'.
[61] Deloitte (2019), '2019 Deloitte and MAPI Smart Factory Study: Capturing value through the digital journey'.
[62] European Commission (2022), 'Smart manufacturing'.
[63] European Commission (2022), 'Robotics | Shaping Europe's digital future'.

solutions to various societal challenges from ageing to health, security, energy and environment.[64] Significant benefits can also arise in other sectors and contexts, such as healthcare (e.g. for training and remote surgery) and education (e.g. for smart learning environments with personalised adaptive learning frameworks), as well as for emergency response (e.g. for sharing real time high resolutions images with remote experts for a more effective and optimal response/action) or for the development of smart cities.[65]

2.3 Metaverses

What is the need?

Online interaction is evolving to provide more immersive and interactive experiences. The creation of metaverses is currently described as an immersive and constant virtual 3D world, where people interact by means of an avatar to carry out a wide range of activities, from socialising to working together and virtual travel.[66]

In light of the extensive potential benefits that the metaverse could entail, the European Commission has shown great interest in the development of the metaverse. Various initiatives have been launched to promote a European way to foster virtual worlds, relying on three pillars: people's safety in virtual worlds, cutting-edge technologies and sustainable ecosystems, and resilient connectivity infrastructure.[67]

From a technical perspective, the metaverse is at the intersection of extended reality (VR and AR), meta-worlds (the systems/platforms) and web3 with the virtual assets economy. Key metaverse characteristics are currently described based on four specific technical features:[68]

- realism—enabling full emotional immersion in the virtual world;
- ubiquity—accessible through all devices at all times with one virtual identity;
- interoperability—allowing information exchange and interaction between distinct systems;
- scalability—the ability of the network to enable massive numbers of users to occupy the metaverse without compromising the efficiency of the system or the experience of the users.

What does a metaverse need?

It is currently uncertain as to what will be required to guarantee the delivery of these features, as a precise description of the metaverse is

[64] ibid.
[65] Mashaly (2021), op. cit.
[66] European Parliament (2022), 'Metaverse: Opportunities, risks and policy implications', Briefing, 24 June.
[67] European Commission (2022), 'People, technologies & infrastructure – Europe's plan to thrive in the metaverse I Blog of Commissioner Thierry Breton'. See also European Commission (2022), 'The Virtual and Augmented Reality Industrial Coalition | Shaping Europe's digital future'. An upcoming non-legislative initiative on virtual worlds is expected in 2023. The European Parliament has also launched an initiative procedure on 'Virtual worlds: opportunities, risks and policy implications for the Single Market'.
[68] European Parliament (2022), op. cit.

not yet available. Indeed, requirements will likely be specific to each application, its algorithms, its processes and functions, and the end-user target quality.[69]

However, given the many possibilities it promises, the widespread adoption of the metaverse will highly depend on the quality of fixed and mobile networks in terms of latency, symmetrical bandwidth and overall speed, and on the reliability of these quality parameters.

In particular, the metaverse is likely to need high bandwidth (more than 2 Gbps in the long term) to cope with the massive data streams that will inevitably be generated, and low latency to capture real-time reactions—likely in the 10–50ms bracket.[70] VR/AR industries agree that application latency should be less than 20ms,[71] while research shows that due to the size and position of the displays, a latency below 15ms is needed to avoid motion sickness induced by VR.[72] Moreover, certain applications (such as remote surgery that could be delivered with the use of metaverses) are expected to need even lower latency requirements—e.g. below 0.75ms.[73]

Moreover, security will be essential, especially when metaverse services are used for sensitive interactions, or to protect user privacy. Indeed, the high volume of data used in the metaverse raises a number of data protection and cybersecurity issues, such as how to protect avatars against identity theft.

Most importantly, making the metaverse a reality will require a global effort. A number of different players—at the levels of content and experience, services, hardware and infrastructure—will have to work together to bring it to reality.

Device manufacturers will need to collaborate with content providers and ISPs in order to bring new applications to end-users. VR/AR devices will be a key driver of the development of the metaverse once technological challenges are overcome (e.g. form factor, optics, and battery life). However, to be able to overcome those challenges, manufacturers will need certain guarantees from CAPs and ISPs on the actual viability of the metaverse. For instance, the use of head-mounted displays imposes extremely high resolution needs, beyond even 4K. This requires innovations across the hardware and software stack, as well as improvements in network throughput.[74]

Moreover, collaboration also requires the definition of a common framework to evaluate the capability of end-to-end network,

[69] Ericsson Blog (2022), 'Network performance and the metaverse: Can 5G deliver what's needed?', 30 November.
[70] International Telecommunication Union (2018), 'Service requirements for next generation content delivery networks'. Other sources mention higher requirements, of more that 10Gbps. See Huawei (2022), 'Challenges to Wireless Networks as the Metaverse Becomes Reality', October.
[71] International Telecommunication Union (2018), op. cit.
[72] See Virtual Speech (2020), 'Motion Sickness in VR: Why it happens and how to minimise it', 27 April; Qualcomm (2018), 'VR and AR pushing connectivity limits', October.
[73] 3GPP (2021), 'Study on communication services for critical medical applications', Technical report 22.826 v. 17.2.0.
[74] Meta (2022), The next big connectivity challenge: Building metaverse-ready networks, February.

developing common quality metrics and a common approach to the relationship between network quality of service and user quality of experience.

What benefits could the metaverse lead to?

Although virtual worlds are becoming increasingly popular, due to the uncertainty and the number of challenges that relate to the metaverse, its mass adoption is not expected in the near future.

However, through the development of the metaverse over the next years, the potential benefits that may derive from it can involve more immersive interactions (e.g. in gaming and entertainment), better collaboration in business interactions, enhanced learning opportunities, and health-related benefits.[75]

Indeed, the metaverse can open possibilities across many sectors, from healthcare to online education or (making learning easier and more entertaining). Indeed, the metaverse can open endless possibilities across many sectors, from healthcare to online education (making learning easier and more entertaining) or training (e.g. the US Army is exploring using the metaverse to establish a virtual environment for soldier training).[76]

Furthermore, virtual worlds can also be set up by firms and public administrations, or for political purposes.[77] For instance, virtual workspaces could help to develop better engagement, collaboration and connection opportunities for employees.

Notwithstanding the potential negative mental and physical health implications that may derive from its excessive use, the metaverse can also have beneficial effects on health. First of all, the metaverse could enhance interaction opportunities and more inclusive experiences for people with mental or physical disabilities. Moreover, virtual worlds could contribute to the delivery of healthcare and improved patient safety, through virtual therapy and remote surgeries and diagnosis, as well as better patient monitoring.[78]

Finally, the potential social benefits that can be derived from the metaverse will grow with the degree of its adoption. Enabling its large-scale adoption could even help to mitigate certain concerns regarding the potential for social exclusion due to the relatively high costs of access to the metaverse (e.g. schools in poor districts may not be able to afford it). Moving away from the metaverse being a niche product will likely reduce costs and lower barriers to entry, translating into greater and more widespread social benefits.

[75] European Parliament (2022), op. cit.
[76] European Parliament (2022), op. cit.
[77] European Parliament (2022), , op. cit.
[78] Omnia Health (2023), 'How virtual reality and the metaverse can improve patient safety', May.

2.4 Cloud gaming boost

What is the need?

Cloud gaming is a new way to access gaming applications that is device-agnostic and operates entirely on the cloud server side. [79] This means that images are rendered, compressed and transmitted to the user's device without requiring additional hardware setup. Its applications go beyond recreational and entertainment as it can also be used for educational purposes.

However, cloud gaming requires a fast and reliable internet service to download applications, install updates or engage in live online competitions. Despite the rising popularity of competitive games and growing numbers of gamers, the quality of experience of mobile users is limited by the quality of their connection since highly interactive applications require more power than what current mobile broadband can reach.[80] In particular, lag and delays in gameplay are a serious issue as they can degrade the user experience and reduce customer retention.

This could be addressed with changes in how mobile users connect to the cloud gaming platform. For particular applications, the gaming provider could offer a temporary boost in the quality of connectivity to enhance the user experience. Cloud gaming boosts would be particularly useful in situations that require especially high levels of certain quality parameters, such as latency or download capacity. For instance, this is the case if a user wants to download a new extension of an application while on the go, or if they want to take part in a one-off live competition.

What do cloud gaming boosts need?

First, to match the performance of a console system or high-end gaming computer, a cloud platform must be able to deliver enough computing power to guarantee a latency-free gaming experience.

Indeed, low latency is the number one requirement for a successful cloud gaming business. The ability to instantly process the actions of a user when interacting with other players in the same game is key to offer a more immersive, lag-free experience. It is estimated that time-critical cloud games involving fast multiplayer interactions will require below 20ms end-to-end network latency for a quality experience.[81]

Second, high-quality video transmission requires large bandwidth support and high throughput—otherwise video compression degrades the user experience, in particular for VR and highly interactive games. Some cloud gaming platform providers recommend 10Mbps reliable downlink throughput as the minimum for games to be played over a mobile network for a good quality of experience (QoE) on a smartphone. However, games with complex graphics require an average of 15Mbps throughput with peaks of 25Mbps or more.[82]

[79] Roach, J. and Parrish, K. (2021), 'What is cloud gaming', DigitalTrends, March.
[80] Ericsson (2020), 'Mobile cloud gaming – an evolving business opportunity'.
[81] Spirent (2022), op. cit.
[82] Ericsson (2020), op. cit.

Furthermore, transmitting high-resolution graphics and audio fast enough for smooth gameplay can be very data-hungry. For instance, it is estimated that streaming games consumes several times more data than a video stream of equivalent quality.[83] Therefore, an additional requirement for the development of cloud gaming is the increased download capacity.

What benefits it can lead to?

Cloud gaming boosts could improve gameplay experience for players for recreational and entertainment purposes, as well as enhancing other potential benefits such as developing motor skills, and creativity.

Cloud gaming boosts could enable the creation of higher-quality games, as well as innovative and impressive gaming environments, which could also attract new users with a higher willingness to pay. This, combined with the ability to access games using any device (which reduces the cost of hardware setup and storage), would help to bring extra value to the cloud gaming market.

All these considerations are particularly relevant in light of the growing importance of the gaming industry. At the global level, the cloud gaming market is estimated to reach $22.53bn, with 58.75% CAGR by 2030.[84] Moreover, the European Commission has recently launched an initiative aimed at increasing the capacity of European video game producers, extended reality (XR) studios and audio-visual production companies to develop games and interactive immersive experiences with the potential to reach global audiences.[85]

Finally, cloud gaming boosts could also allow a more extensive uptake of cloud gaming for other uses (e.g. in education and in the media and advertising sectors), further contributing to the growth of the cloud gaming market. For instance, the Joint Research Centre of the European Union has studied the possibility of using video games in education and reducing the risk of exclusion of vulnerable groups, and finances projects related to the use of video games in education.[86]

Research shows that cloud gaming could solve most of the present challenges of using games in education (e.g. technical, competency and qualitative and financial problems), while increasing student motivation, helping them to achieve better results, and improving social and intellectual skills, such as communication, adaptability and resourcefulness, as well as reflexes and concentration.[87]

[83] Ericsson (2020), op. cit.
[84] Market Research Future (2022), 'Cloud Gaming Market Size to Reach USD 22.53 Billion, With a CAGR of 58.75% CAGR by 2030'.
[85] Creative Europe Programme (2022), 'Video games and immersive content development'.
[86] See: Wastiau P, Kearney C, Van den Berghe W. (2009), How Are Digital Games Used in Schools, Brussels: European Schoolnet; Barr M. (2017), Video games can develop graduate skills in higher education students: A randomised trial, *Computers in Education*, **113**, pp. 86–97.
[87] See: Suznjevic, M. and Home, M. (2020), Use of Cloud Gaming in Education, in Game Design and Intelligent Interaction; Squire K. (2003), Video games in education. *International Journal of Intelligent Games & Simulation*, **2**:1, pp. 49–62.

3 Changing networks and policy considerations

The selection of use cases we highlighted in section 2 indicate that internet networks are expected to change in the future. The consequent policy implications should be considered **now** to avoid present or forthcoming policies limiting or preventing innovations that could be beneficial to all actors and consumers.

Based on our analysis of the selected use cases, two key directions are emerging:

1. new value creation could be unlocked through new models of collaboration between actors in the internet value chain, including through ISPs adopting multi-sided business models;
2. users could demand different quality levels; if network providers could enable this, innovative services could benefit all actors in the value chain, including consumers, through more choice and access to innovation.

3.1 New models of collaboration that unlock value creation

The first insight highlighted by the case studies we selected is that some future applications of the internet might not be delivered unless new and closer forms of collaboration between multiple providers in the internet value chain are deployed.

By adopting new collaboration models with application providers, third-party providers and device manufacturers, ISPs could encourage initial take-up of an application by end-users and unlock investment in new services or applications.

Encouraging take-up of new applications

Connectivity has been a catalyst for European society and the economy, allowing for innovation that in turn enhances consumer welfare. To continue enabling innovations, the networks of the future would have to evolve to match the future needs of users.

ISPs can potentially unlock value by addressing coordination and hold-up issues caused by demand uncertainty among actors in the internet value chain.[88] For example, by partnering with other players in the value chain to offer mutual certainty, they can overcome gridlock situations where consumers are unaware of the importance of a service and do not purchase high-quality connectivity packages; content providers hesitate to launch applications; and device manufacturers postpone or abandon projects due to lack of connectivity and lack of developers creating applications for their product.

Commercially, this could take the form of an agreement where an application provider agrees with an ISP to offer a connectivity with a

[88] See for example Teece, D. J. (1992), Competition, cooperation, and innovation: Organizational arrangements for regimes of rapid technological progress, *Journal of economic behavior and organization* **18**: 1, pp. 1–25; or Niels, G., Jenkins, H. and Kavanagh, J. (2016), Economics for Competition Lawyers, second edition, Oxford University Press, section 6.2.

specific level of quality to a small group of users on a temporary basis to gauge interest and understand willingness to pay by end-users. In this arrangement, the ISP will have a multi-sided business model proving services to both end-users and business users at the same time. For example, in the cloud gaming boost use case, the gaming provider will be able to use the network of the ISPs for its own delivery of a quality boost to a specific number of users, without the need for end-users to change their retail package to try out the enhanced gaming features.

Likewise, applications in metaverses that bring together consumers in a professional capacity (i.e. as employees) could benefit from arrangements where the ISP has a commercial relationship with the metaverse provider that charges employers a subscription to deliver a guaranteed quality to the employees that are spread out in a region or country.

The advantage for the employee is that they could test out new ways of working without the need to obtain an enhanced connectivity package just for one application. On the other side, the metaverse provider could benefit from such an arrangement through increased confidence that investments in the development of the application will have an available market. Moreover, it would benefit from the network effects that early adopters of a technology provide for the wider application.[89] Building a user base is an important factor in the growth of platforms such as metaverses, and this could explain why the metaverse provider would be interested to subsidise the initial take-up by end-users.[90]

As the number of applications with specific quality requirements that a user can access increases, the collaborative arrangement might cease to provide the highest level of benefits to all the parties involved. Once the proof of demand is generated, the specific quality requirements might become part of a public internet retail offer where the ISPs contract directly only with the end-user.

Other arrangements could see closer collaboration between ISPs and third-party providers. For example, the third-party providers could rent networking infrastructure with well-defined quality parameters from the ISPs in order to create a bespoke infrastructure for a manufacturing plant that uses autonomous vehicles, digital twins and AR/VR technology for quality optimisation.

The network-as-a-service (NaaS) business model

At the basis of the model described above is the newly developed multi-sided business model of the 'network-as-a-service' (NaaS).[91] NaaS is a cloud-enabled, usage-based consumption model that allows users to acquire and orchestrate network capabilities without owning,

[89] Eisenmann, Thomas, Geoffrey Parker, and Marshall W. Van Alstyne (2006), Strategies for two-sided markets, Harvard business review 84, no. 10: 92.
[90] Rochet, Jean-Charles, and Jean Tirole (2003), Platform competition in two-sided markets, Journal of the European Economic Association 1, no. 4: 990-1029.
[91] Ericsson Blog (2019), Non-standalone and Standalone: two standards-based paths to 5G.

building, or maintaining their own infrastructure.[92] This means that the user of NaaS can have more control and more visibility over how their content is delivered to end-users and enable them to innovate based on new capabilities.

This new flexibility and capabilities of network slicing allows operators to expose network capabilities to enterprise customers (B2B or B2B2C customers) in a programmatic manner (through APIs), offering them consumer-like experiences with choice, scalability, visibility and control. This exposure allows for service-tailored network programmability and frictionless network application integration, strengthening ties between operators and enterprise customers for service (and value) co-creation.

According to a 2022 survey by CISCO on a panel of over 1,500 IT leaders, demand for NaaS is driven by the need to continue to deploy the latest networking technologies in their organisation or due to the risk of security attacks.[93]

3.2 Quality differentiation: more choice and innovation

The second insight revealed by the selected use cases is that some firms will want to provide their users with a higher level of quality.

While the focus until now has been on throughput, the applications of the future seem to require networks to deliver on other dimensions (e.g. low latency and jitter, guaranteed security and availability) in addition to high throughput. The case studies we included in our selection, as well as others from industry reports,[94] highlight that this need is anticipated for a subgroup of internet users, especially as applications become more dynamic. Being able to request a tailored network specification that matches the specific needs of an application will give customers more choice and enable their access to new innovations.

First, not all users have the same requirements, and the networks of the future can address this by tailoring the services they offer. For example, some applications are predicted to become more dynamic by requiring continuous processing of high throughput data at the edge of the network as in the case of optimised manufacturing plants. Other use cases using the same infrastructure can be specified for a very secure connection, but without latency requirements, such as for banking data or sharing sensitive files.

This quality differentiation is expected to be possible with the development of 5G networks due to their structure, which allows slicing according to a user's own unique characteristics and resources.[95] Network slicing would allow network operators to create customised network experiences for different types of users or applications by allocating the appropriate resources and capabilities to each slice. This will lead to an efficient use of network resources by

[92] CISCO (2022), 2022 Global Networking Trends Report Special Edition: The State of SASE and The Rise of Networking as a Service (NaaS), henceforth Cisco (2022).
[93] CISCO (2022).
[94] Ericsson 2021, Network slicing: Top 10 use cases to target.
[95] Ericsson, 5G vs 4G: What is the difference?; Ericsson (2021), The essential building blocks of E2E network slicing.

those who need it, when they need it. This would combine the advantage of a dedicated line of access with the efficiency of flexible allocation to maximise utilisation of the infrastructure.

A similar approach could be delivered for the fixed networks using software that allows the virtual dimensioning of the network to comply with specific required needs. This could be delivered as an enhanced capability of what is currently offered to some enterprise users. For example, an increase in cyber-attacks is prompting more firms to add additional security services from ISPs.[96]

The idea that greater differentiation benefits consumers by offering them increased choice has strong support in the economics literature. Both theoretical and empirical studies show that providing consumers with a broader set of choices enable a better match between their choice and their preferences, increasing consumer welfare.[97]

Second, quality differentiation can also lead to new product innovation.[98] As highlighted in section 2, the first wave of demand is likely to come from businesses that need to ensure a certain level of quality connectivity on the go, beyond the well-defined fixed physical location that characterises enterprise connectivity now. As such, the inability to have guaranteed parameters for an application could lead to some applications not being able to come into existence.

For example, low latency can be an essential requirement in the case of autonomous vehicles in order to prevent accidents. Without a guarantee of low latency enabling fast data processing at the edge while the vehicle is on the go, the benefits of this new user mobility form or for transport fleet providers will not materialise.

Finally, while delivering low latency through quality differentiation can provide benefits to all actors in the value chain and all kinds of CAPs, it is particularly important for smaller CAPs. This is because larger CAPs have potentially other ways to directly improve the QoE for the end-users consuming their applications and content (e.g. investments in own infrastructure such as submarine cables, or CDNs). On the contrary, smaller CAPs rely more heavily on the quality of the services provided by ISPs and improvements in the 'last mile' quality will have a higher impact on their overall service.

[96] Based on information received from Liberty Global.
[97] See: Mussa, M. and Rosen, S. (1978), Monopoly and Product Quality, *Journal of Economic Theory*, **18**:2, pp. 301–317; Salop, S.C. (1979), Monopolistic Competition with Outside Goods, *The Bell Journal of Economics*, **10**:1, pp. 141–56; Brynjolfsson, E., Hu, Y. and Smith, M.D. (2003), Consumer Surplus in the Digital Economy: Estimating the Value of Increased Product Variety at Online Booksellers, *Management Science*, **49**:11, pp. 1580–96; Botti, S. and Iyengar, S.S. (2006), The Dark Side of Choice: When Choice Impairs Social Welfare, *Journal of Public Policy & Marketing*, **25**:1, pp. 24–38.
[98] See, for instance, Shapiro, C. (2011), Competition and Innovation: Did Arrow Hit the Bull's Eye?, in Lerner, J. and Stern, S. (eds), The Rate & Direction of Inventive Activity Revisited, National Bureau of Economic Research, University of Chicago Press.

3.3 Policy implications

The selected use cases we highlighted in this paper point to a future where developments in network technology can enable new value when deployed through new business models that offer quality differentiation to users. Future innovations and use cases will most likely go further than the examples we covered here; however, to the extent that they have similar underlying needs for guaranteed quality, we consider that regulation should support and encourage these possibilities as long as certain criteria are met. Ideally these criteria should be principles-based to allow for dynamic regulation that in turn promotes innovation and investment.

There are multiple sector-specific (ex-ante) rules that apply to ISPs (and some to other actors), most importantly the European Electronic Communications Code and the Open Internet Regulation (OIR) and general competition law. The OIR is most relevant to the use cases we discuss in this paper as it aims to safeguard user access to the open internet, ensuring that all internet traffic is treated equally and without discrimination by ISPs.[99] Nevertheless, the OIR seems to take into account that there are potentially different quality of service requirements in an internet network. From this perspective, the OIR allows ISPs to directly agree differentiated levels of quality with end-users,[100] adopt different traffic management measures,[101] and offer specialised services,[102] provided that it is necessary, proportionate and based on objective needs, and that the general internet is not affected.

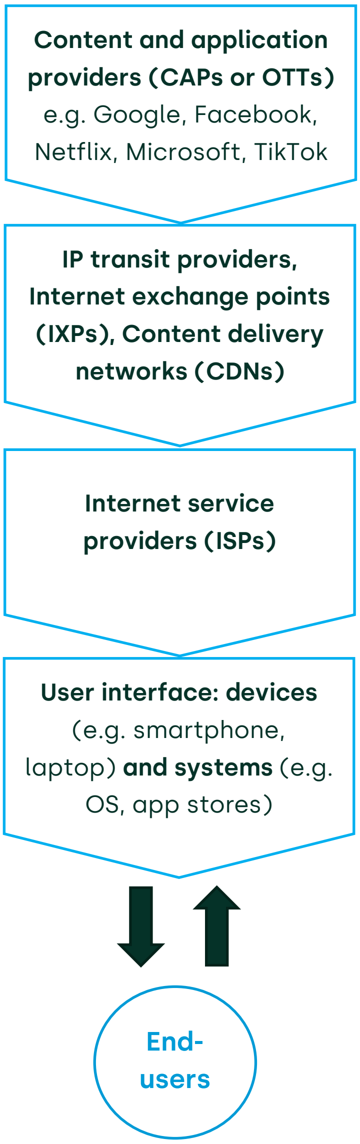
However, we observe that this regulatory framework sometimes seems to be ambiguous and could be interpreted in a narrow way, which could potentially hamper some of the innovations that we have discussed. Where the existing rules are ambiguous and where there is uncertainty, there needs to be room for a discussion between different actors, regulators and policymakers on how to achieve the networks of the future, leaving open the possibility that the current rules need to be clarified, reinterpreted or even adjusted in light of future needs. This dialogue will ensure that the conditions are right and there are no undue risks to either party, contributing to innovative new uses of the internet.

We consider that regulators should adopt a principles- and evidence-based approach when applying these rules to continue to protect businesses and end-users, while enabling the flexibility to explore and implement propositions that create value across the internet value chain. This view is in line with the OIR's objective to 'guarantee the continued functioning of the internet ecosystem as an engine of innovation'.[103]

[99] European Parliament and of the Council (2015), Regulation (EU) 2015/2120 of the European Parliament and of the Council, henceforth referred to as Open Internet Regulation.
[100] Open Internet Regulation, Art. 3(2).
[101] Open Internet Regulation, Art. 3(3).
[102] Open Internet Regulation, Art. 3(5).
[103] Open Internet Regulation, Recital 1.

A1 The collaboration behind the public internet

The Internet value chain



The public internet is a global network of interconnected computer networks that use the standard Internet Protocol (IP) to link devices worldwide. The internet carries a vast range of information resources and services from one location to another by breaking them down into small packets of information that are transmitted independently to their destination, once a route has been identified.

The public internet is a constantly evolving and dynamic infrastructure that relies on the cooperation and collaboration of many different participants (see figure on the left). The main participants include the following.

- **Content and application providers (CAPs)** provide the applications or content that are distributed to and consumed by end-users on top of the network provider's infrastructure.[104]
- **IP transit providers** provide international connectivity by allowing the interconnection at internet exchange points (IXPs) of several networks, including regional networks, undersea cables, bilateral international terrestrial cables and satellite links.
- **Content delivery networks (CDNs)** provide networks of geographically distributed servers that store non-real-time content (e.g. web pages, images and videos) for local consumption.[105]
- **Internet service providers (ISPs)** provide connectivity services and access to the internet, either through a fixed connection (typically with Wi-Fi) into a user's home or wirelessly to a mobile device. Their network architecture consists of access (the 'last mile' connection to end-users), backhaul (between the access network to its core network) and core (or backbone that comprises high-capacity links used to move data over large distances).
- **Device manufacturers and systems operators** provide the physical devices through which applications are connected to the internet.
- **End-users** are both consumers of internet access and senders of information—the latter of whom can be categorised as 'content providers' in certain situations, especially following the adoption of increased homeworking following the COVID-19 pandemic.[106]

Alongside the connectivity provided by ISPs to end-users, there is also the business connectivity often provided through dedicated (leased) networks. In general, this is delivered with a guaranteed level of quality in terms of bandwidth, availability, or other parameters. This guarantee is typically above the public internet parameters, which are provided on a best-effort basis.

[104] These include video on demand (VOD), social media, gaming, messaging, search, ecommerce and payments, news, and government services. In principle, every website from which the content consumed by end-users originates can be considered as a CAP.
[105] Examples of CDNs are Akamai, AWS, and Limelight. Internet Exchange Points (IXPs) provide the locations where the different networks of CAPs, ISPs and CDNs can connect with each other
[106] WIK (2022); Feldmann, A.et. al. (2020), The Lockdown Effect: Implications of the COVID-19 Pandemic on Internet Traffic, IMC '20: Proceedings of the ACM Internet Measurement Conference, pp. 1–18.

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