NEXT-GENERATION BROADBAND ROADMAP 2023 TO 2030

SETTING OUT A DETAILED ROADMAP FOR THE BROADBAND NETWORK TO 2030

WORLD BROADBAND ASSOCIATION

This report sets out the World Broadband Association's (WBBA) roadmap for the future broadband network of 2030 and beyond.

Additional WBBA members: Telecom Egypt

Observer:

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EXECUTIVE SUMMARY

Broadband networks have already developed massively since the first deployments in the early 2000s, evolving from networks offering hundreds of kilobits per second to today's more fiber-based networks with a global average speed of 200Mbps. In the last five years alone, the average broadband speed has increased by over 500%, and in some countries (such as China) by as much as 3,000%.

However, pushed by the continued increase in the number of connected devices, the evolution to higher and higher video quality standards and other more bandwidth-hungry applications, and the shift of intelligence to the cloud, the demands on broadband networks are only set to further accelerate. Moving forward though, high speed will not be the only important network KPI. Tomorrow's consumer and enterprise applications will also demand ultra-low latency and high levels of reliability and service consistency. Networks will be expected to operate with a high level of autonomy, have awareness of their surroundings through greater sensing technology, and be highly secure and sustainable.

The evolution to the next generation of broadband networks is therefore complex. This white paper aims to set out a detailed roadmap for broadband networks from 2023 to 2030 and beyond, building on the World Broadband Association's "Next-Generation Broadband Roadmap" report that set out a framework around six dimensions: ultra-enhanced speeds; ultra-reliability and consistency; enhanced connectivity; trustworthy and green; greater intelligence, and greater sensing capability.

KEY MESSAGES AND RECOMMENDATIONS

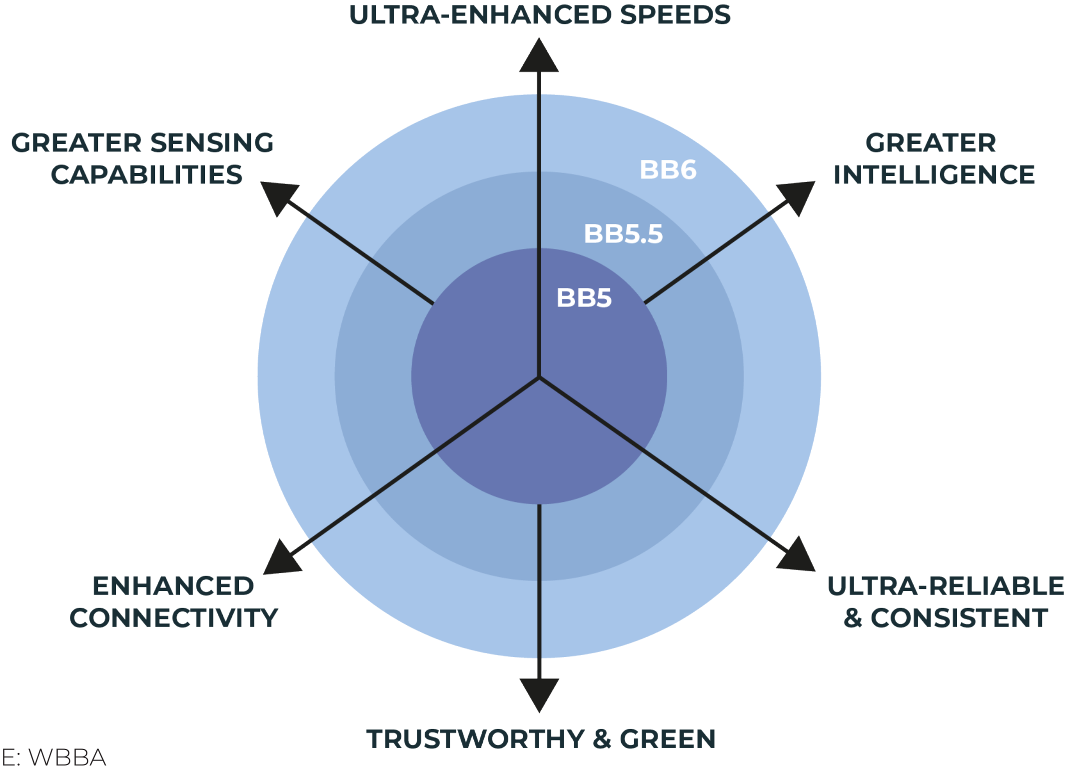
- Largely driven by the Internet of Things (IoT), the number of connected devices is going to increase exponentially. However, besides the rapid growth, the types and capabilities of the connected devices will also evolve as new technology such as 8K video, extended reality (XR), and 3D screens enter the mass market. This increase, multiplied by the trend in more bandwidth-hungry applications in addition to a greater reliance on the cloud, will drive the need for multigigabit networks.
- As the industry evolves to 2030, the focus for operators will no longer just be on top-line speed. Although speed is important for the delivery of some applications, especially video, other applications are far more reliant on other metrics such as latency and jitter. Broadband networks must be capable of handling traffic for all such applications, ensuring that all are delivered at the best service quality level possible. Measuring and ensuring end-to-end quality of experience (QoE) on a per application basis has therefore become an essential metric for service providers.
- The move to more advanced internet applications has already driven advances in the broadband network with residential users in key countries such as Canada, China, France, Japan, South Korea, and the US already being offered subscriptions for multigigabit broadband service to the home. The move to next-generation technologies such as FTTx and DOCSIS 3.1 has also reduced average latency and jitter in such networks. However, the development of broadband networks is not equal. Even by 2030 it is expected that more than 90% of households in Africa, Middle East, and Central & Southern Asia will still be on broadband speeds of less than 1Gbps.
- The next generation of the internet will be highly reliant on advanced broadband network capabilities. Those countries that are lagging behind in rollout will therefore find themselves at a disadvantage in comparison with the most advanced countries, which could severely hamper their socioeconomic development.
- In addition to broadband being essential to the daily lives of consumers, enterprises in all verticals will become heavily digitized, adopting cloud services and technology as well as industrial variants of consumer technology to help their business.
- Advanced broadband networks are also essential for the development of other sectors: high-performance computing has the potential to greatly improve the efficiency of key technologies such as artificial intelligence (AI) and data processing. To achieve this, high-bandwidth, low-latency, and highly reliable data center interconnect (DCI) networks are required to effectively share computing resources and facilitate fast data transfer between both virtual and physical data centers.

- Although tomorrow's broadband networks will be built around the same core network architecture, it is clear that requirements will be very different in different sectors. In this version of its roadmap, the World Broadband Association (WBBA) has therefore split its technical characteristics into two parts: one for the residential market and one for enterprise and vertical industries. Each is summarized below and then set out in detail later in this report:
    - Broadband generation 5.5 (BB5.5), standardization 2023–27
        - Reference characterization: 10G broadband
        - Reference bandwidth: 5–25Gbps (residential, per user); 2Mbps–400Gbps (per service, per enterprise)
        - Several quality and energy-oriented improvements
        - Broadband generation 6 (BB6), standardization 2027 and beyond
    - Reference characterization: multi-10G broadband
        - Reference bandwidth: 25–100Gbps (residential, per user); 2Mbps–800Gbps (per service, per enterprise); 3.2Tbps (data centers)
        - Several quality and energy-oriented improvements
- There are already a number of standards organizations that are defining the different technologies covered in the WBBA's generation roadmap. These include but are not limited to ETSI's ISG F5G & F5G Advanced, ITU-T's SG15, Broadband Forum's standards around the access network, IEEE's standards for Ethernet and Wi-Fi, and the IETF's standards around the internet protocol suite as well as management protocols and data modeling languages.
- Though the 2030 network is seen as far away, the industry needs to study the broadband network evolution toward 2030 and beyond. The R&D for those technologies being standardized in 2030 is currently ongoing, therefore the WBBA will steer the industry direction. A more long-term vision is a good claim and will benefit the whole industry.
- With the migration to all fiber networks, the phaseout of copper is important to create a return on investment and to benefit from lower energy usage.

THE BROADBAND ROADMAP

The scope of the WBBA's 2030 broadband roadmap is described in terms of six dimensions as illustrated in **Figure 1.**

FIGURE 1: THE WBBA NEXT-GENERATION BROADBAND ROADMAP



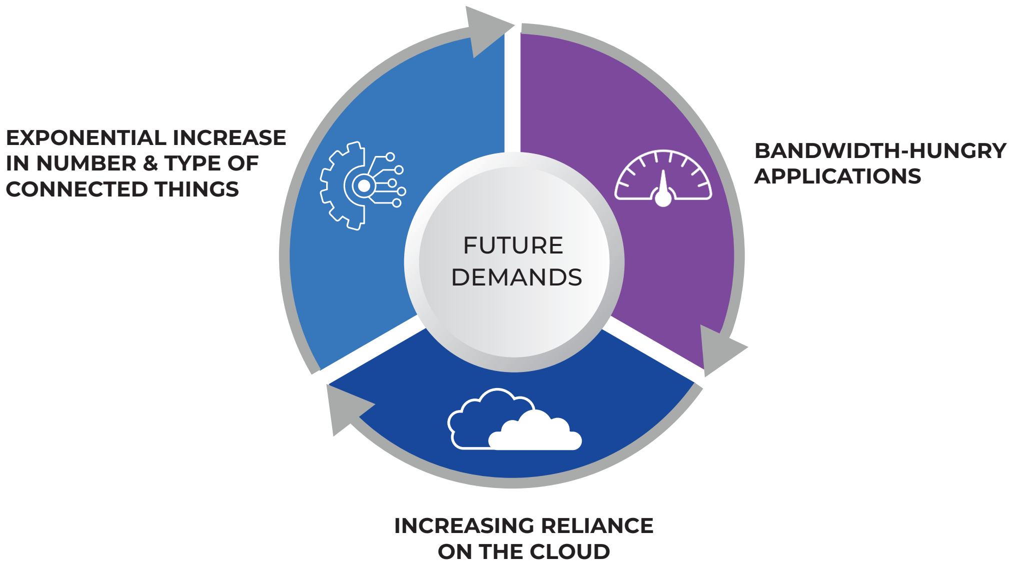
SOURCE: WBBA

- **Ultra-enhanced speeds.** Application bandwidth has been growing at a rate of about 40% per year, and this is expected to continue. Omdia forecasts that by 2030 over 40% of consumer broadband subscriptions will be for speeds of 1Gbps plus.
- **Ultra-reliable and consistent.** The emergence of UHD immersive-experience services is a major driver for the reduction of latency in networks. Other important drivers include industry applications where the communication is mainly between machines, usually requiring immediate action-reaction times.
- **Enhanced connectivity.** Both the network scope and number of endpoints are expected to be increased to support more services and coverage and the ongoing cloud-network synergy that is built on the underlying network. Between now and 2030, shipments of connected devices will have increased by over 40% and installed consumer IoT products by 210%. The types and capability of connected devices will also have changed, with the majority of shipments of display devices having full-HD or ultra-HD capability and shipments of virtual reality (VR) devices outstripping those of games consoles.
- **Trustworthy and green.** As networks and applications become ubiquitous in the future, the network attack surface will grow exponentially and change constantly. Security must be able to respond quickly to changes in the network and service environment while protecting user privacy. The transition to green energy is a global challenge. ICT and, specifically, future broadband networks can contribute significantly to a more sustainable world, both directly by shifting to more energy-efficient network technologies and indirectly by enabling more energy-efficient practices in other sectors.
- **Greater intelligence.** To operate computer-integrated networks, we need to increase the autonomous levels to high autonomy. This allows for self-configuration, self-healing, and self-optimization in network operation. This in turn improves the user experience and service quality.
- **Greater sensing capability.** Optical sensing technologies introduce a new dimension to networks by enabling awareness of the surrounding environment and the fiber infrastructure. This will leverage enhancements in network operations and will add value to network resources through the development of new services.

SERVICE DEMANDS IN 2030

The increasing demands on the network are driven by a combination of the continued growth in the number and variety of connected devices, more bandwidth-hungry applications, and greater reliance on the cloud thanks to the pursuit by application developers of a cloud-first strategy.

FIGURE 2: FUTURE DEMANDS ON THE NETWORK WILL BE DRIVEN BY A COMBINATION OF FACTORS



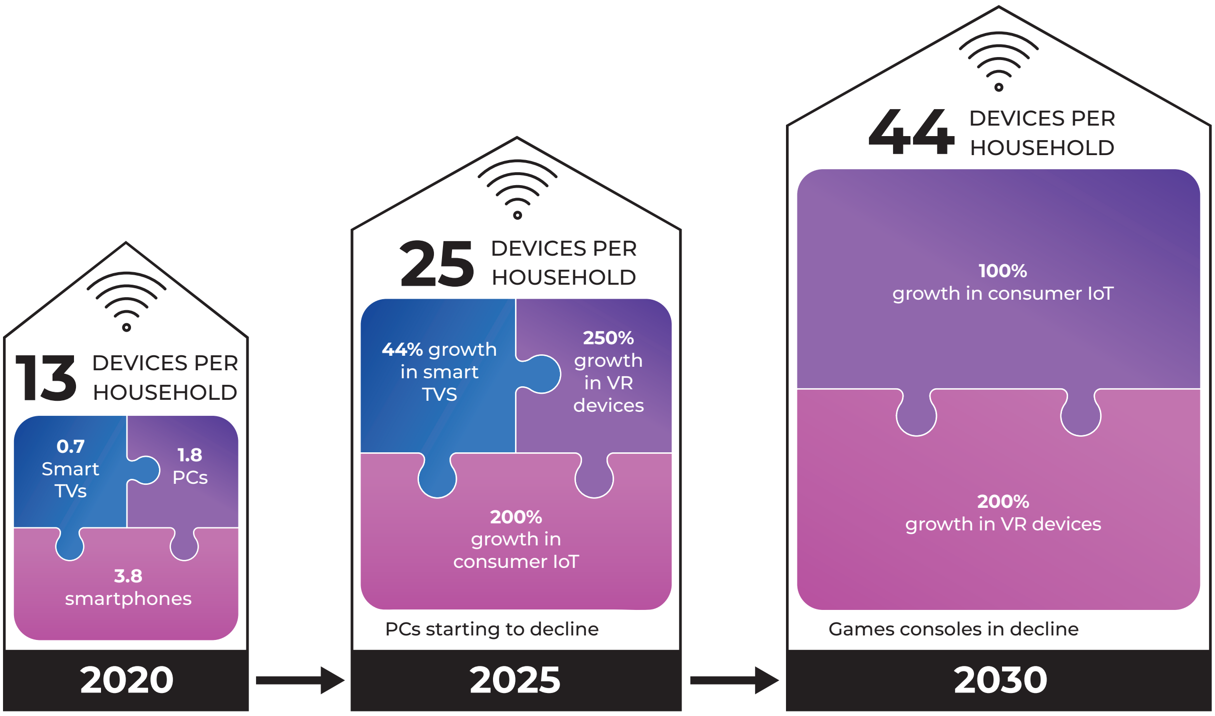
SOURCE: WBBA

CONTINUED GROWTH IN THE NUMBER AND VARIETY OF CONNECTED DEVICES

Between now and 2030, the total number of shipments of connected devices will have grown by over 40% and installed consumer IoT products by over 200%. The types and capabilities of the connected devices will also have changed, with the bulk of shipments of display devices having full-HD or ultra-HD capability and shipments of VR-capable devices outstripping those of games consoles.

The average number of installed connected devices per broadband household has doubled between 2020 to 2025, and will be 80% bigger again by 2030, jumping from 13 in 2020 to 44 in 2030. The bulk of these connected devices will be IoT devices, sensors, and other household items such as appliances and health and fitness products. However, there will also be significant increases in the number of smart TVs, and newer devices such as VR headsets.

FIGURE 3: THE NUMBER OF CONNECTED DEVICES PER BROADBAND HOUSEHOLD WILL DOUBLE EVERY FIVE YEARS



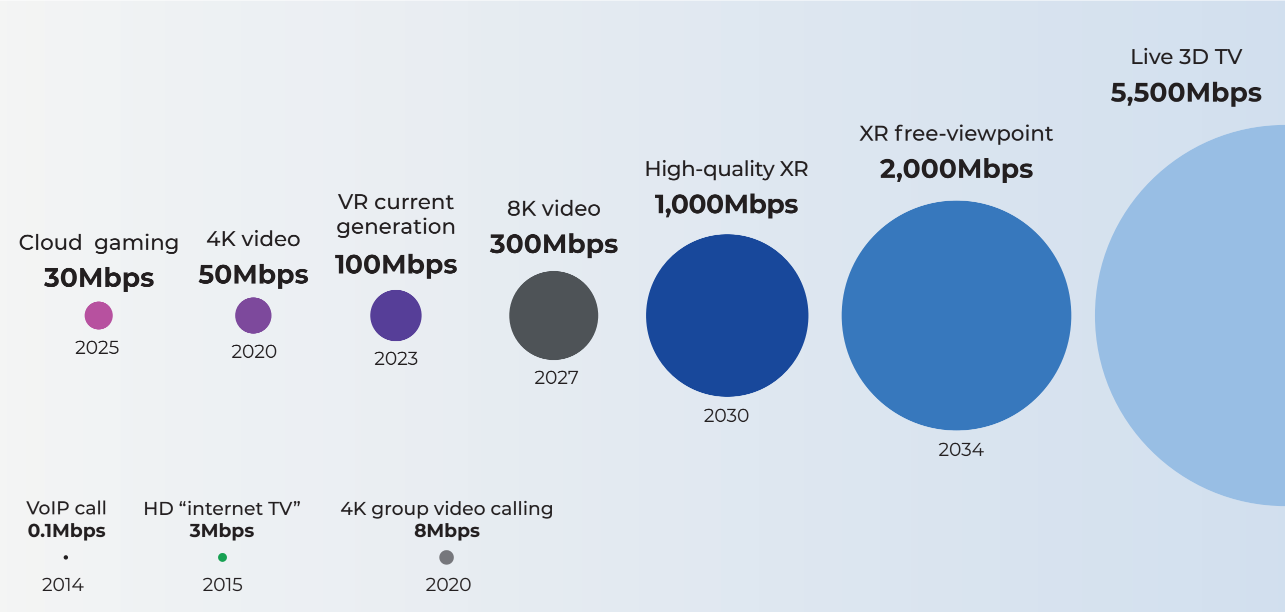
SOURCE: OMDIA

THE DRIVE TO MORE BANDWIDTH-HUNGRY APPLICATIONS

Largely thanks to the gradual move to higher and higher video definition and the introduction of new XR technology, applications will become increasingly bandwidth hungry. Using compression techniques, today's video-streaming services can offer HD video using less than 5Mbps, but high-quality 4K video streams can require speeds of up to 50Mbps and 8K video streams up to 300Mbps (see **Figure 4**).

XR technologies will see a further step change in terms of network demand. Advanced applications could require speeds of 1–2Gbps as well as a maximum, and consistent, latency of less than 3ms. Today, augmented reality (AR) glasses and mixed reality (MR) headsets are almost entirely used for enterprise applications; however, consumer VR headsets are becoming more common, largely because of increased investment from organizations such as Meta (Facebook). Consumer-grade AR glasses are also expected to go mainstream from 2025 onward.

FIGURE 4: FUTURE APPLICATIONS' DEMANDS ON THE NETWORK WILL GROW

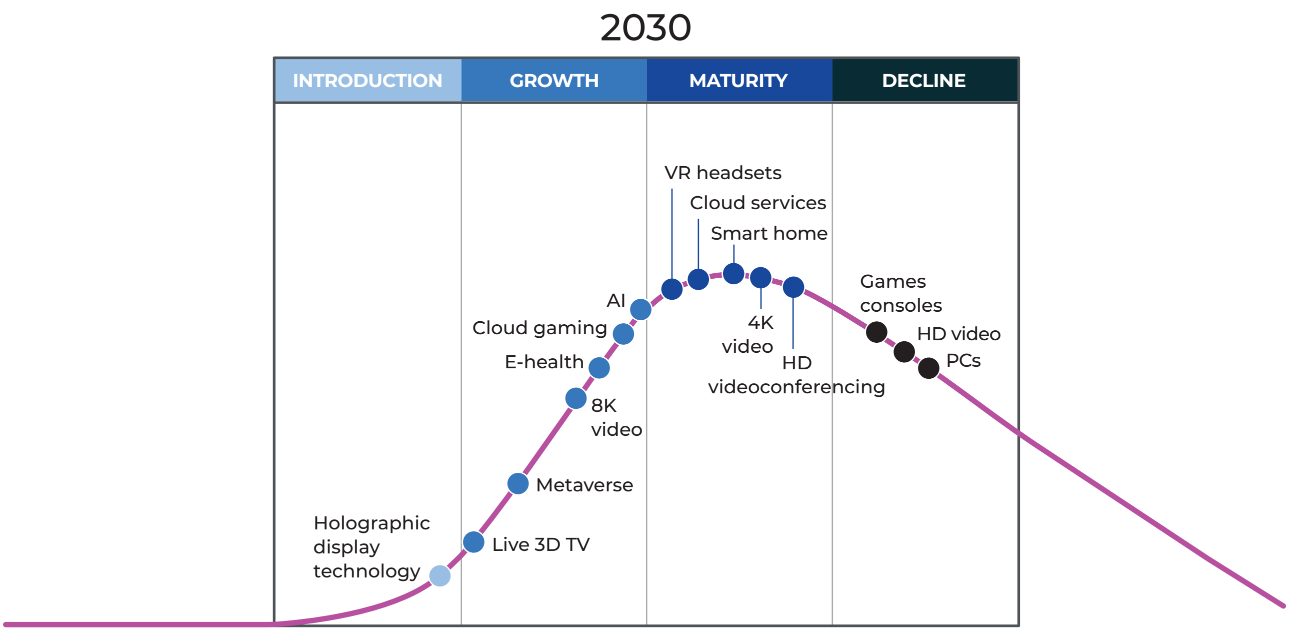


SOURCE: OMDIA

XR TECHNOLOGIES ARE STARTING TO MATURE BY 2030

By 2030, applications such as VR, 4K video, and smart home will be mature and used by mass-market consumers and enterprises alike. Other applications such as cloud gaming, e-health and 8K video will be accelerating rapidly, with live 3D TV and holographic displays in early rollout (**Figure 5**). It is therefore clear that if customers are to be able to use several of these advanced applications concurrently, the development of broadband networks must continue so that all households and businesses, not just the highest-spending ones, can benefit from such innovative services and applications.

FIGURE 5: TECH LIFECYCLE BY 2030



SOURCE: WBBA

CLOUD-NETWORK CONVERGENCE: THE KEY TO MEETING SERVICE DEMANDS

In the face of complex and diverse digital scenarios, the current approach of independent resource provisioning falls short of maximizing its value. There is a need for a closer integration and ultimate convergence of cloud and network infrastructures. Cloud-network convergence will become a critical feature of the new information infrastructure. Such convergence will serve as a driving force for the digital economy and enable the seamless connectivity of an intelligent world, analogous to how the power grid accelerated the second industrial revolution.

In the coordinated development process of cloud and network, the cloud makes demands on the network in terms of network performance, availability, intelligence, adaptability, and security. Equally, the network, because of its cloudification, also makes higher demands on the cloud in terms of unified networking and intensive operation capabilities, open and enhanced capabilities of virtual network elements, and telecom-grade security.

Ultimately, the cloud and network achieve the following capabilities:

- **Integrated supply:** combining network resources and cloud resources in the definition, request, and orchestration, forming a unified, agile, and elastic resource supply system
- **Integrated operation:** transitioning from independent operation systems for the cloud and network to domainwide resource awareness, consistent quality assurance, and integrated planning and operations management
- **Integrated services:** achieving unified acceptance, delivery, and presentation of cloud and network services to customers, realizing deep integration between cloud services and network services

THE MOVE TO THE CLOUD

Over the years there has been a push for greater intelligence to be located in the cloud. This has several advantages, including reducing customer premises equipment (CPE) costs and being able to support advanced technologies such as big-data analytics and new cloud services. However, as more applications start to rely on real-time communication, bandwidth, latency, and service consistency becomes an issue.

There has been more a recent trend around network edge, pushing the portions of an application that require ultra-low latency as close to the customer as possible while maintaining the overall advantages of the cloud.

With the increasing rollout of all-optical fiber and 5G networks, some of the requirements for network edge start to fade, and reliance on the cloud will once again increase. The balance between centralized and distributed services will depend on a mix of technical and economic factors.

Locating more intelligence in the cloud increases cloud server costs where it can be hard to achieve economies of scale, a fundamental requirement of most broadband service business models, especially around IoT. There is an argument, therefore, for keeping at least some of the intelligence in the local area network, which in addition to reducing service costs keeps customer data securely located in the customer’s own network. Applications that can benefit from edge computing include data acquisition and local processing (e.g., for robotics and industrial automation), data analytics, and location services. However, as CPE devices become smaller with less compute power of their own, reliance on the cloud is only going to increase.

The multicloud transformation trend of global enterprises is also increasing significantly. The proportion of multicloud utilization is expected to exceed 80% by the end of 2023. The computing power used by a typical enterprise is diversified in several categories, and in the future, AI computing power will expand to reach 46% of total capacity by 2025.

The network plays a crucial role in this computing power. It is estimated that by 2030, a single data center will have 1 million computing nodes. A 1 in 1,000 network packet loss rate would result in a 50% computing power loss. Congestion caused by unbalanced workload can cause up to 70% loss of AI computing power. In addition, computing power will be more distributed in the future, and high-quality requirements will be extended not only to data centers but to the entire wide area network (WAN). The future network, therefore, must be capable of application and computing awareness, with deterministic latency and higher reliability.

EVOLUTION OF CLOUD SERVICES

The evolution of cloud services is expected to develop into the following areas:

- The cloud is massively increasing the available compute power, and the compute power gets more diverse, from generic compute to AI. The overall effect is that the compute infrastructure will become more diversified. Most compute is relying on the timely delivery of data of some sort or is accessing large data stores in the networks. There are, therefore, higher requirements for bandwidth and determinism for intracloud and intercloud networks.
- The as-a-service model of cloud will show more diverse cloud services, hosted on a variety of specialized platforms and offered by different cloud service providers. Therefore, several cloud infrastructures of different players may be used depending on the application or for geo-redundancy reasons. Those cloud infrastructures may interact across infrastructures and across different cloud service providers. Network operators may need to build networks that can link different cloud service providers.
- Distribution of computing has benefits and drawbacks. The benefits are that it is more reliable, can be allocated nearer to users, and allows for better optimization. The drawbacks are that the multiplexing gain is typically not that large, the operational complexity is higher, and the resource planning is more complex. The trade-off of where to locate compute infrastructure and where to deploy cloud workloads is becoming a far more multidimensional optimization problem taking the latency requirements for receiving a reply, redundancy aspects, and green energy availability into account. Distribution of computing often leads to load splitting, with some data uploaded to the central cloud and some transmitted to the edge cloud through network elements such as the 3GPP User Plane Function.
- To run mission-critical workloads, the network needs to be able to provide mission-critical communication capabilities, and it needs to follow the virtualization trend from the cloud to the network, separating different portions of networking traffic from each other when the traffic belongs to different cloud services or cloud service customers.
- The cloud technologies are used for the more optimized operations of networks on the networking as well as on the service layer. Cloudification of network elements can increase network flexibility, scalability, and efficiency while reducing costs and complexity. It can also facilitate the deployment of new services and applications and improve user experience and satisfaction.

THE NEED FOR HIGH QUALITY OF EXPERIENCE FROM END TO END

The number and variety of internet applications continues to grow, and broadband operator networks must be capable of carrying traffic from multiple services, all with different service characteristics, to different users over a single network. Moreover, with the continuous development of internet applications, it is common for the same user to use different services at different times. Therefore, it is necessary to meet the different (QoE) needs of users in different service scenarios.

Each internet application has its own set of service key performance indicators (KPIs), which can be linked to the key network characteristics required to deliver them. However, there are two further requirements that are essential to supply this level of experience. One is consistency: cloud gaming, for example, relies on an uninterrupted and consistent level of connectivity, with drops in latency having a great impact on the gaming experience.

The other is time: although traffic patterns can and do change, there are still peaks and troughs throughout any day. The video operators will change their QoE requirements accordingly at different times. Network operators must be capable of responding to this service variation in time.

ON-DEMAND END-TO-END CONNECTIVITY

QoE is significantly affected by QoS KPIs. For example, the user's web-browsing, video-streaming, gaming, and cloud services experience may all be heavily affected depending on actual, average, or median values but, most importantly, on the stability of those KPIs over time, especially during peak hours.

To guarantee the stability of the QoS KPIs and meet the consistent characteristic of the service, technology that delivers on-demand end-to-end connectivity is needed.

FINE-GRAINED LIFECYCLE MANAGEMENT

To meet the in-time characteristic of the service, fine-grained lifecycle management technology is needed to control and manage the service lifecycle, including service establishment, maintenance and terminated in time. Furthermore, to fulfill "in time," "fully automatic" and "high efficiency" are needed.

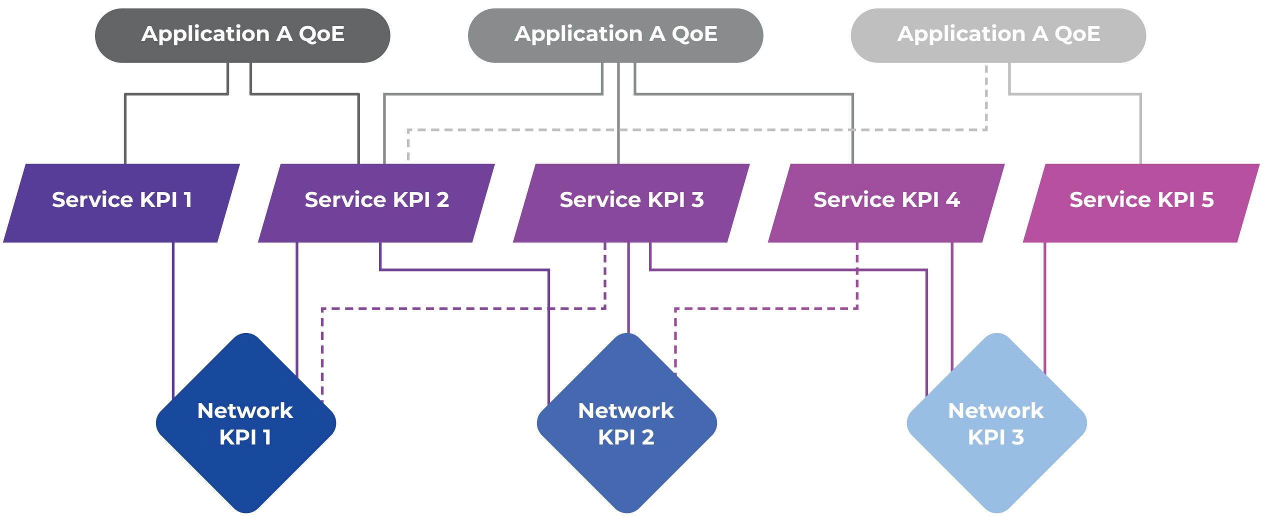
NETWORK AS A SERVICE

The network-as-a-service (NaaS) concept complements the cloud computing paradigm, enabling the customer to build their end-to-end service with proper characteristics of the network and of the compute. It is fundamental for network operators to implement technologies capable of complying with dynamic KPIs that vary to fulfill customer demand over time. End-to-end network slicing—including RAN/Wi-Fi, fiber to the room (FTTR), fixed access, core, and transmission—enables network operators to deliver connectivity with the proper service-level agreement (SLA) to the business (e.g., unmanned industry, augmented reality) and consumer (e.g., gaming, virtual reality), respecting net-neutrality principles.

APPLICATION QOE REQUIREMENTS

There is a direct link between the end user's experience of the application and the performance of the network delivering it. Of course, the end user's experience is subjective and is based on individual perceptions. However, in general, methods such as Mean Opinion Score (MOS) have been used in the communications industry for many years to measure QoE. This can then be related to the required service KPIs to meet that experience, which in turn can be related back to the final network KPIs (**Figure 6**). For example, for a video-streaming application to receive a MOS rating of 5 (very good), one of the service KPIs might be a maximum initial buffering time of 100ms. Meeting this service KPI will require certain network KPIs such as the minimum bandwidth necessary to meet that buffering time limit. According to end-to-end network-slicing logic, a specific set of KPIs must be defined for each kind of network slice.

FIGURE 6: RELATIONSHIP BETWEEN QOE, SERVICE KPIS, AND NETWORK KPIS



SOURCE: WBBA

TABLE 1: EXAMPLE SPEED AND LATENCY KPIS FOR HIGH-QUALITY EXPERIENCE OF SELECTED APPLICATIONS

APPLICATION	BANDWIDTH	LATENCY
HD VIDEO CALL	8Mbps	<20ms
CLOUD GAMING	30Mbps	<20ms
4K VIDEO	50Mbps	<50ms
8K VIDEO	300Mbps	<50ms
HIGH-QUALITY XR	1,000Mbps	<3ms

SOURCE: WBBA

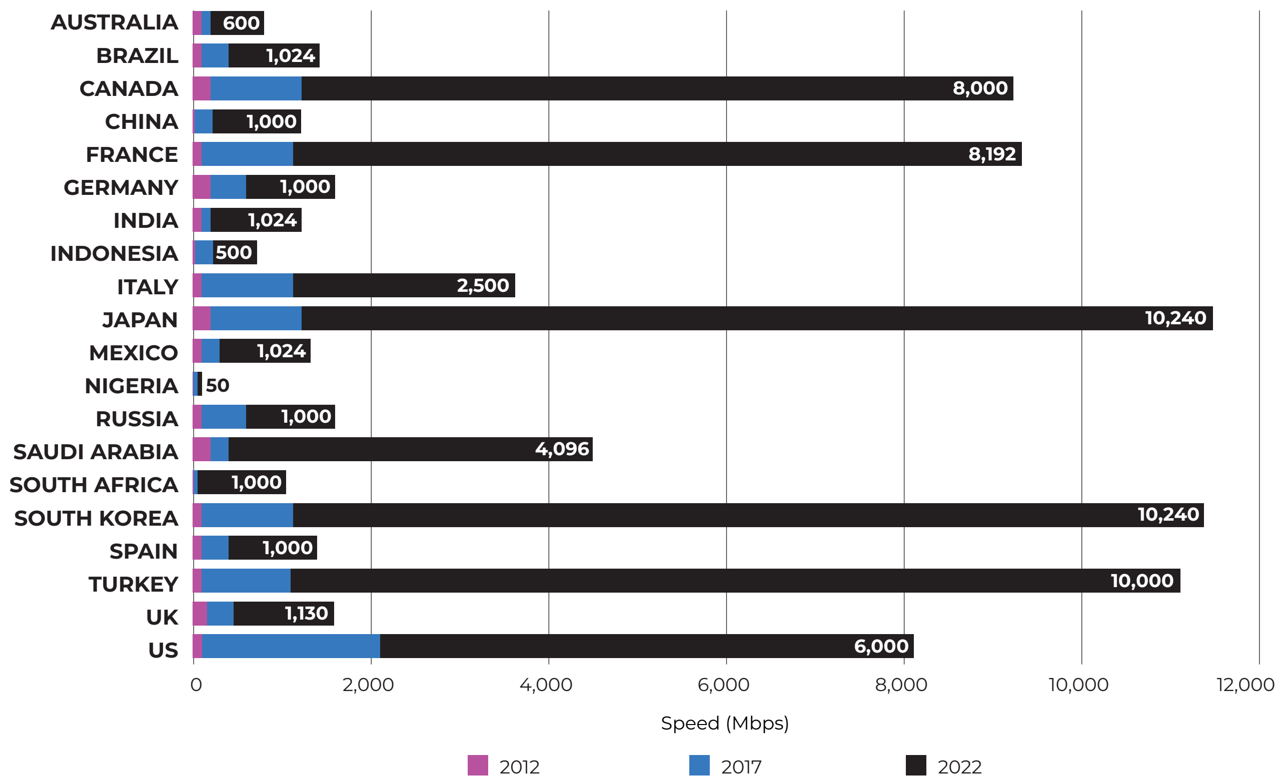
MEETING THE DEMANDS OF APPLICATION CONCURRENCY

Based on data from Omdia, the average number of connected devices per broadband household at end-2022 was 17 and includes 3.8 smartphones, 1.8 computers, and 0.9 smart TVs. In more developed countries, or high-end households, the average number will be higher and the mix different. It is already a reality, therefore, that in developed markets households can have multiple HD video streams, online gaming sessions, and videoconferencing calls, all happening concurrently. “Super user” households will own far more connected devices and be using an even greater number of concurrent apps than the average.

It is important to match and guarantee the fulfillment of the KPIs requested by each service running on each device. For complex devices such as PC and smartphones, multiple connections with a dedicated set of KPIs will need to be activated. End-to-end network slicing, with a smooth handover from fixed connectivity to the mobile network (either for backup or mobility reasons), will need to be granted, implying high synergies across multiple access types.

This concurrent application demand has already seen a rapid increase in broadband network capability, with gigabit speeds now available in many markets and top markets already offering 10Gbps services (see **Figure 7**).

FIGURE 7: THE BROADBAND SPEEDS BEING OFFERED CONTINUE TO RISE

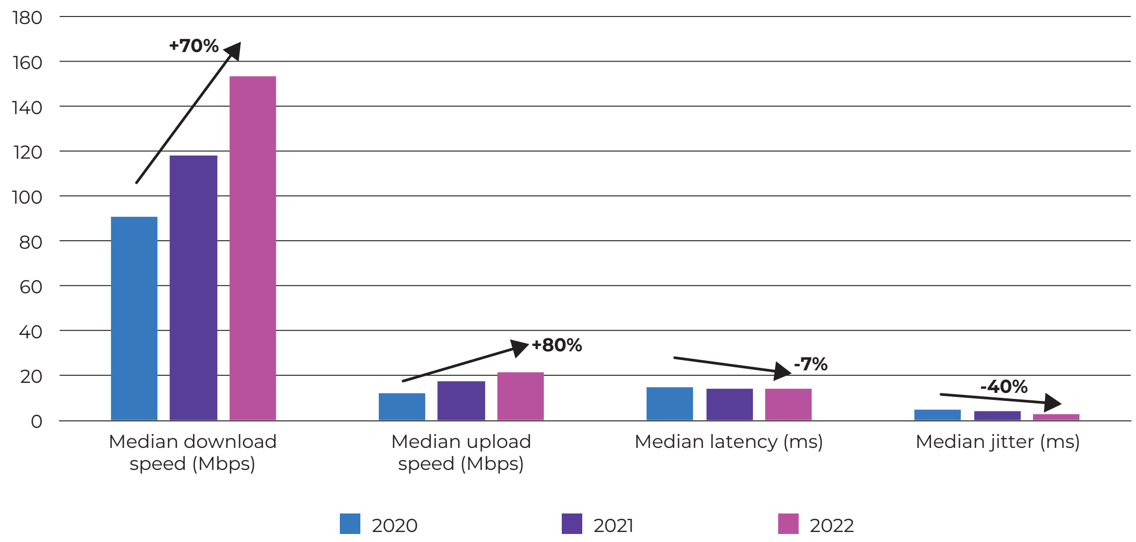


SOURCE: OMDIA

This increase in broadband network capability has been driven by the move to next-generation broadband access technologies such as fiber to the home (FTTH) and DOCSIS 3.1 cable. At the end of 2022, 67% of global consumer broadband connections were FTTH; by 2030 this share will have risen to 77%.

The move to more advanced broadband technologies has pushed not just the maximum speeds offered but also the overall average and has improved other metrics such as latency and jitter. For example, in the US, median download speeds have increased by 70% in just two years, with median latency falling by 7% and median jitter by 40% (**Figure 8**).

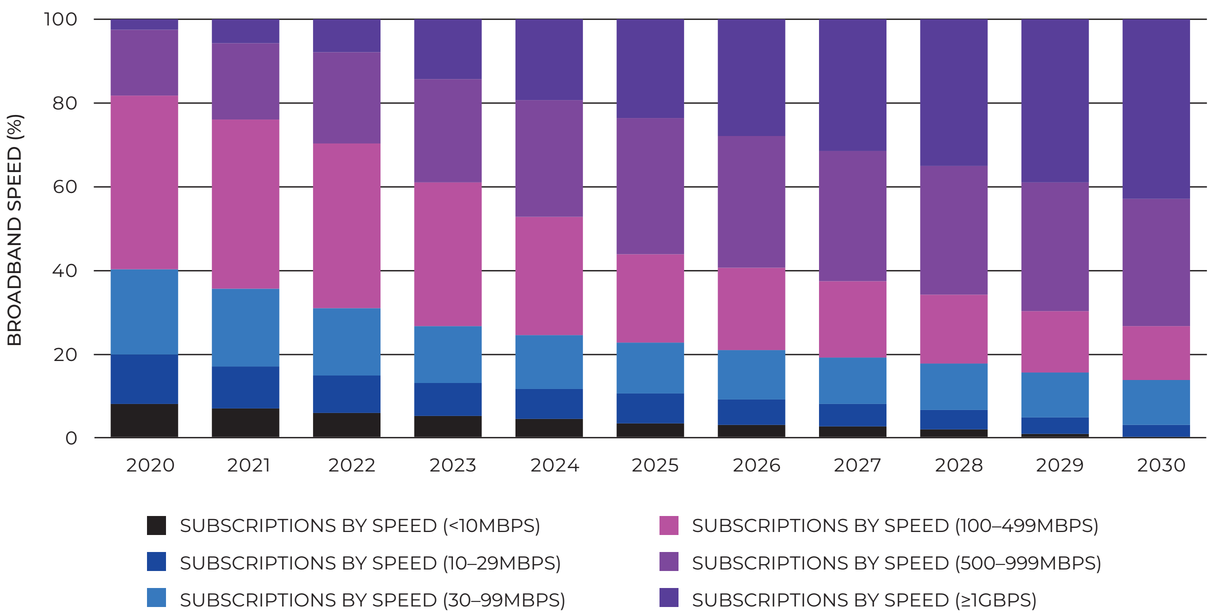
FIGURE 8: BROADBAND NETWORKS ARE QUICKLY DEVELOPING TO MEET CONSUMER DEMAND



SOURCE: OOKLA

The uptake of those top-speed gigabit services will continue to grow. At a global level, 43% of all broadband subscription services are expected to be on tariffs offering broadband speeds of 1Gbps or more. Only 27% will be on services with speeds of less than 500Mps.

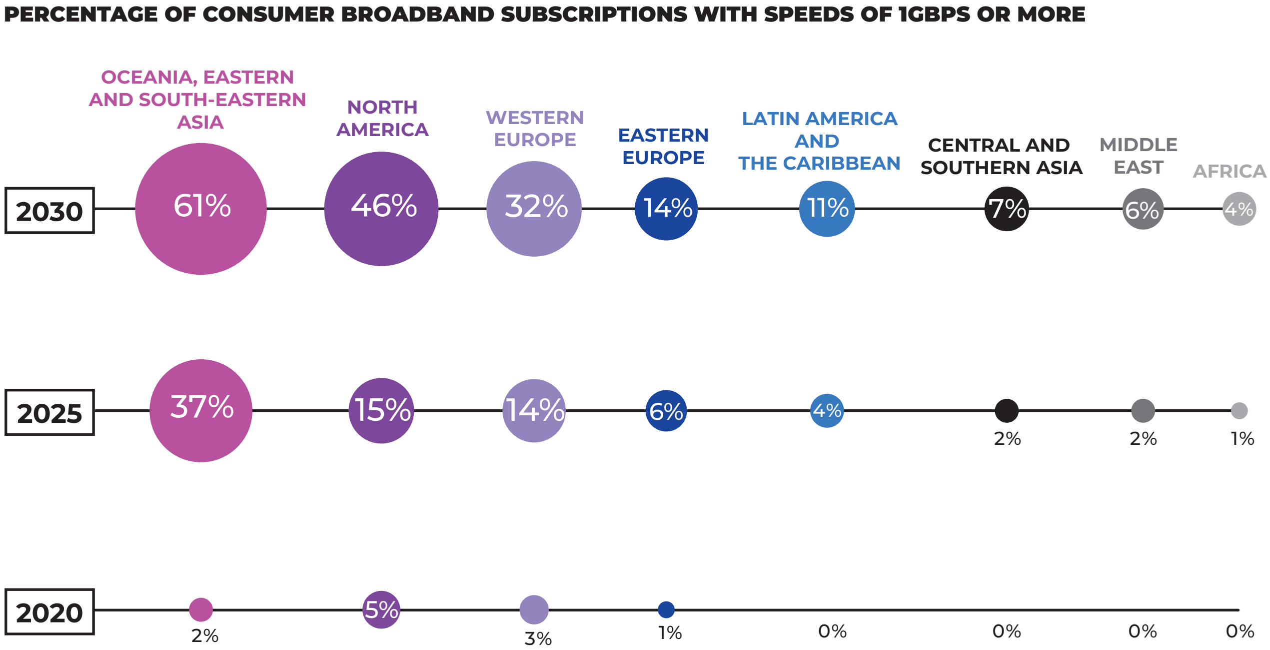
FIGURE 9: GLOBAL BROADBAND SUBSCRIPTIONS BY SPEED, 2020–30



SOURCE: OMDIA

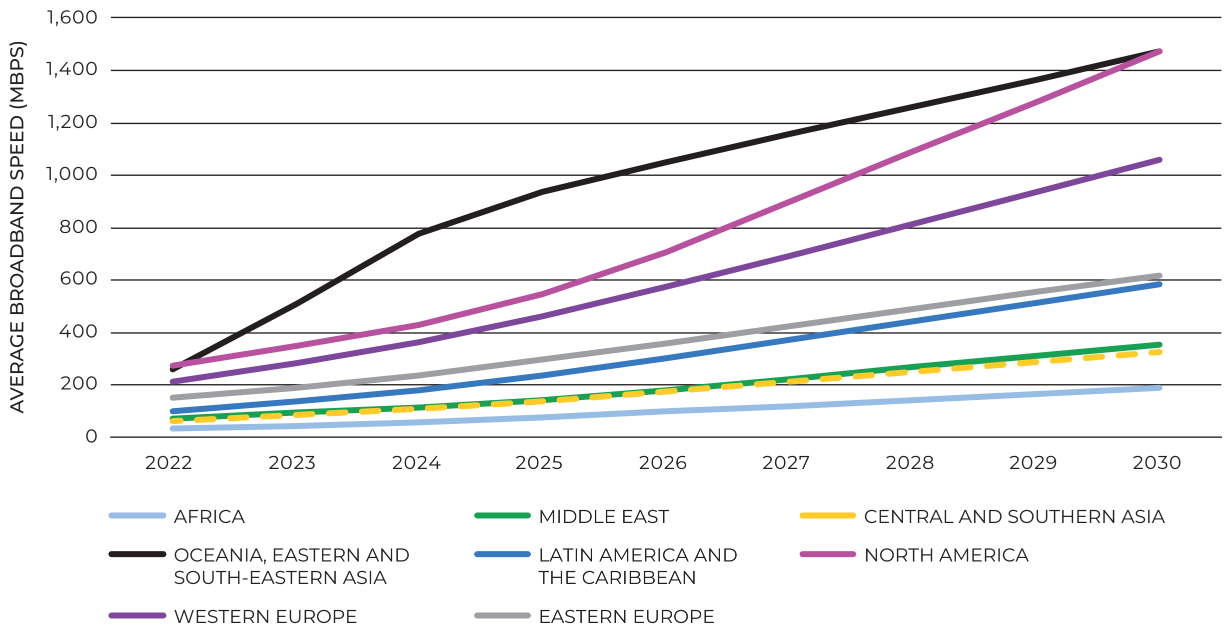
However, the global picture hides the fact that the actual availability and take-up of ultra-high-speed services is weighted toward developed markets, with much lower availability in emerging markets. By 2030 only 4% of broadband connections in Africa are expected to receive gigabit services, compared with 61% in Oceania, Eastern & South-Eastern Asia and 46% in North America. This discrepancy in top speeds also plays out in terms of average speeds, which will exceed 1.4Gbps in Oceania, Eastern & South-Eastern Asia and North America but reach only 200Mbps in Africa.

FIGURE 10: THE GAP BETWEEN DEVELOPED AND DEVELOPING BROADBAND NATIONS IS SET TO WIDEN



SOURCE: OMDIA

FIGURE 11: THE GAP BETWEEN AVERAGE SPEEDS IN DIFFERENT REGIONS WILL ACCELERATE THROUGH 2030



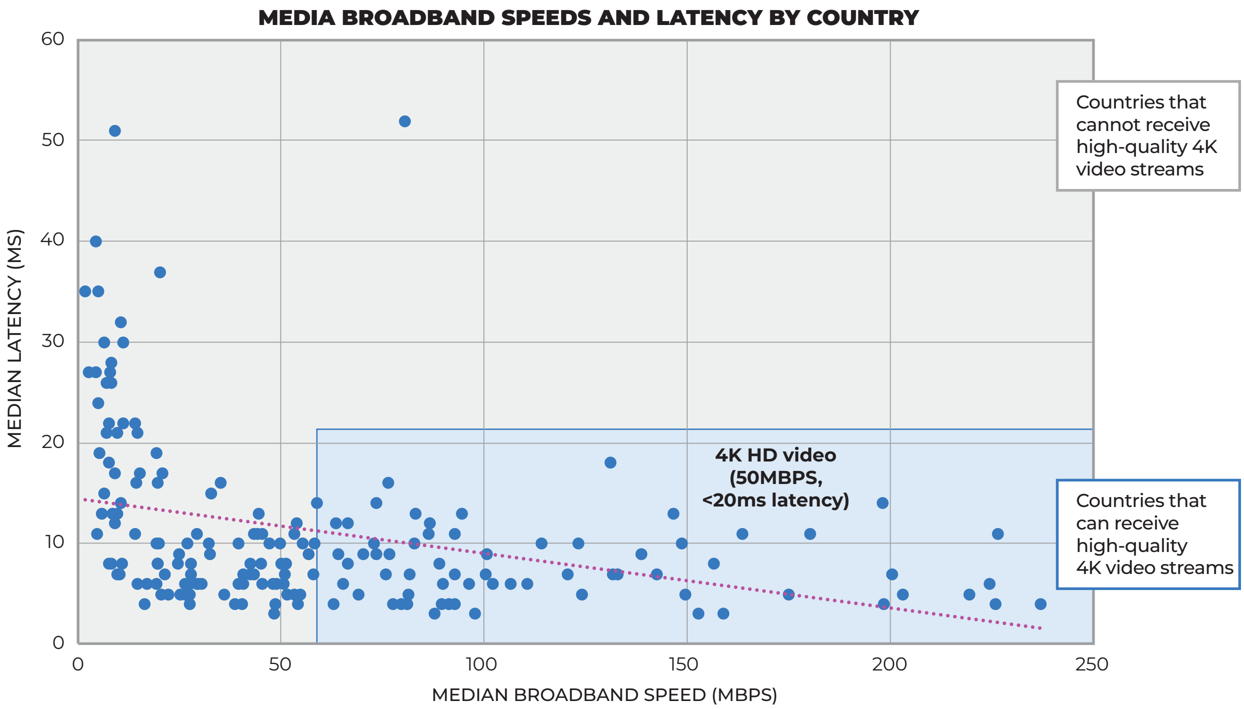
SOURCE: OMDIA

THE DIGITAL-DIVIDE FOCUS WILL SHIFT FROM ACCESS TO CONNECTIVITY TO APPLICATIONS

It is now well understood that a high level of broadband penetration is critical to a country's socioeconomic development. However, the quality of that broadband connection is just as important as fact of the connection itself. Unlike other utility services such as gas and electricity, with broadband the quality of network is important because higher-speed, lower-latency networks can support a greater number of, and more sophisticated, cloud-based applications. This wider, more advanced set of internet applications can help further drive a country's wealth and overall efficiency.

Figure 12 illustrates that based on the application network KPIs detailed in **Table 1**, the average household in 60% of countries today would not be able to receive a top-quality HD video stream, and in 40% it would not be able to receive high-quality cloud gaming. As the world becomes more reliant on advanced Web3.0-based applications, not just for entertainment but for work, education, socializing and health, it is imperative that all countries migrate toward full gigabit speeds to ensure that all citizens can get equal access to such technology and services.

FIGURE 12: MANY COUNTRIES CANNOT SUPPORT HIGH-END APPLICATIONS TO THE AVERAGE BROADBAND HOUSEHOLD



SOURCE: OOKLA, OMDIA

SERVICE CHARACTERISTICS FOR BB5.5 AND BB6

THE DIGITAL CONSUMER IN 2030

THE CONNECTED CONSUMER

In 2030, networks will have expanded from connecting individuals and homes to connecting things, from everyday objects (in and out of our homes) to items that we wear and even integrate with our bodies. By 2030, there will be 13.7 million new consumer devices connected daily, with a total of more than 9 billion consumer mobile connections and 33 billion consumer IoT devices. Most of these devices will rely, at least for part of the time, on home broadband connectivity.

This level of connectivity will create a world where digital information and content are ever present and instantly accessible. Additionally, the way we experience the internet will have changed fundamentally from largely 2D experiences today to having the digital and physical worlds merged through the use of AR or fully immersive 3D experiences via a mix of AR and VR known as mixed reality (MR). By as early as 2026, there will be more VR headsets connected than Xbox game consoles.

THE IMMERSIVE CONSUMER

This evolution in connectivity, alongside developments in Web 3.0 technology, will change how people socialize, work, and consume entertainment services. Virtual and immersive experiences will be created, enabling consumers to replicate in the digital world everything they do in the physical one. Social aspects of life, such as healthcare and wellness, will also have evolved, not only in the way people interact with healthcare professionals but also because of the myriad personal connected devices in use, including mirrors, weighing scales, cameras, and wearables. These devices can monitor and measure current health conditions and spot potential health issues without the need for a doctor's appointment, thus saving the health industry billions of dollars annually.

Outside the home, digital consumer experiences will be ubiquitous as internet services and applications adapt to specific devices and local network capabilities. Objects such as cars will also be fully connected, directly delivering consumer entertainment and applications and communicating with their surroundings for automated driving, smart navigation, and other facilities such as automated payments.

THE SUSTAINABLE CONSUMER

By 2030 sustainability will have become a key element of the consumer's decision-making. Real-time information will enable consumers to understand the environmental impact of each decision they make, and Web3.0 technology will enable new business models that mean that resources are less owned but are recycled, reused and shared, bringing economic benefits to the consumer and reducing their impact on the environment.

THE APPLICATION-DRIVEN ENTERPRISE

For businesses in 2030, cloud services will have been mainstream for more than two decades. Enterprise workloads have shifted almost exclusively to the cloud—or rather a collection of intelligent, interconnected clouds—that adapt to changing application loads, user and device needs; available compute resources; and network traffic conditions. The underlying resources align to meet requirements—application specific and set by the business—for acceptable response intervals and work experiences.

Enterprises still maintain technology departments that will be responsible for IT and operational technology (OT). The technology department assesses new applications, platforms, and solutions in a digital twin environment, which models virtual representations of physical assets such as machines and workspaces, mixed physical/virtual environments such as operational processes, and purely virtual assets such as datasets and software.

Helped by virtualization and intelligent agents, technology workers can manipulate a new solution without having to unbox physical hardware or write code. They can change setups and configurations and adjust interfaces and adapters. They can then test how the configured solution works with existing equipment and software in the twin environment. When an innovation is approved, it is ordered and added into the real world to become part of business operations. The company's knowledge workers access the new capability to benefit the organization.

In 2030, enterprises have widely adopted industrial variants of consumer technologies to help their businesses. The knowledge worker's 2030 toolkit includes MR for complex human visualization and response, AI and machine learning to assist or take over human decision-making, rich data collected from video collaboration and video streams with cognitive analytics, and the metaverse, which is a social space and virtual work environment. Each of these technology underpinnings already existed a decade ago. They have grown significantly in the last 10 years, empowering a new talent pool of enterprise knowledge workers.

For the application-driven enterprise, the data center network (DCN) is an important channel for data transmission. It is also the key to promoting the upgrade of computing power service capabilities of data centers and fully releasing computing power. The DCN connects user terminals and computing and storage devices in the data center to ensure efficient and secure data transmission on network links. Data center networks are classified into data center internal networks. Data center internal networks ensure efficient data transmission between computing and storage devices for efficient service processing. The network between data centers and between data center and users ensures high-speed, agile, secure, and reliable data transmission on the communication network.

With the rapid growth of enterprise cloudification requirements, enterprise and campus access bandwidth requirements are also increasing. Enterprise wireless office gradually evolves to videoconferences, which are mainly used for data downloading. In the future, the penetration rate of VR conferences will increase. Take a typical enterprise as an example. In 2023, the number of concurrent video conferences per 100 square meters has reached more than 30, and the peak number has reached more than 60. The upstream traffic of each access point (AP) in 2023 is 2.5Gbps. By 2027, the penetration rate of VR immersive office is about 10%, and the overall bandwidth requirement will have increased to 10Gbps per AP.

ENTERPRISE VERTICALS

MANUFACTURING

OVERVIEW

Manufacturers ingest goods and materials, processing them into different output materials and goods. The business depends on shop or factory floor operations and needs predictable supplies, reliable and consistent processes, and buyers that accept the output. Uptime and efficiency are critical. Most manufacturers also have extensive policies and compliance requirements around monitoring for worker safety, environmental safety, energy consumption, and emissions.

SERVICE CHARACTERISTICS

Manufacturing has some of the most advanced digital operations in the world, with initiatives such as Industry 4.0. Many modern manufacturing machines already connect through high-performance, high-capacity interfaces. Enterprises may also run wireless private networks on licensed spectrum, which mitigates interference and is easier to secure. The sector is an early adopter of low-latency edge cloud services, deployed onsite or in a low-latency, geographically close data center or cloud site.

One example is an Asian manufacturing enterprise that to be cost effective uses 143 items of AOI (automatic optical inspection) and other equipment per 1,000 square meters to implement high-density product quality. A network with 10Gbps bandwidth is required to enable the high-density access of these quality inspection machines.

FINANCIAL SERVICES

OVERVIEW

Financial services operate some of the most specialized and most complex IT environments in the world. The industry includes insurance companies, retail and commercial banks, specialist investors, capital markets firms, and brokerages. Managing clients' money comes with special government and business restrictions around client security, privacy, and accountability. But at the same time, many financial institutions also have legal requirements around client tracking, reporting, and disclosure.

SERVICE CHARACTERISTICS
Financial services companies have widely different network requirements. At one end is basic, secure internet connectivity to mobile devices and kiosks. They also maintain secure web portals for customers to access accounts. At the other end are high-speed dedicated, highly reliable, and resilient links to and between data centers and financial and trading exchanges.

MINING AND ENERGY

OVERVIEW
The energy industry—oil, gas, and mining—is a vertical of extremes. Extremely rugged, huge-scale industrial equipment is involved in extraction. The industry operates in remote, severe environments: above the Arctic Circle, in remote plains and deserts, and on offshore platforms that reach deep beneath the ocean. These businesses are driven by information that enables them to coordinate their massive operations and run them smoothly. Technology enables them decide where to explore and how to allocate resources. It also helps maintain equipment uptime and ensure worker safety. Environmental impacts need to be monitored and mitigated for compliance. Overall operational efficiency helps the industry remain competitive.

SERVICE CHARACTERISTICS
For the energy industry, just introducing technology into the field is challenging. Unplanned operations downtime is unacceptable, so highly reliable communication networks are essential. A failure in operational technology monitoring, management, or control systems could be catastrophic.

Energy companies also face major challenges in connecting their remote sites. Their headquarters and branches in office buildings are reached by fiber, but remote operations have limited options. Sometimes fiber can reach a remote site, from where the connection can be distributed by a secure wireless network to connect assets. Sometimes fiber is not an option, but terrestrial microwave can backhaul traffic from the site. For other mining facilities and drilling platforms, satellite uplinks may be the only viable option.

HEALTHCARE

OVERVIEW
The healthcare industry comprises organizations such as hospitals, clinics, physicians' offices, and rehabilitation centers that monitor and improve peoples' health outcomes. These organizations draw on a highly skilled, highly specialized workforce that works with expensive proprietary tools, equipment, and software.

IT executives in healthcare are hungry to support standardization through data portability and security, information exchange, and the adoption of valuable new digital applications. But the big ambitions of healthcare IT departments are matched by big challenges. Institutions are weighed down by strict privacy, security, and data compliance requirements and by aging legacy systems.

Unlike in other sectors, most healthcare organizations are centralized operations. But in recent years there has been tremendous consolidation of formerly standalone healthcare providers. Hospitals and offices that were once independent are becoming part of federated groups, and each brings its own history with deeply embedded technologies and IT culture. IT departments need to find ways to consolidate the business without any disruption and appeal to talented medical professionals who can be very resistant to change.

SERVICE CHARACTERISTICS
Healthcare IT executives see digital disruption taking hold in business operations. Across electronic records, connected devices, analytics, and beyond, changes are coming faster, shifting network needs in unpredictable ways. Healthcare executives' response is to turn to practices known as "adaptive networking" that are secure, flexible, and easy to scale and that deliver on performance.

Adaptive networking components include software-defined WAN (SD-WAN); hybrid networks that merge internet virtual private networks (VPNs) and MPLS VPNs; flexible bandwidth, particularly bandwidth on demand; dynamic WAN ports into data centers and clouds; and network functions virtualization. Healthcare institutions combine these components and wrap them with security and reporting intelligence to meet their accelerating IT needs.

For example, a medical supply company in Switzerland focuses on providing network services for medical stores and pharmacists. With the digitalization of healthcare, the headquarters and branches require bandwidth upgrade from 1GE to 10GE. However, customer private lines are expensive. Most customers use SD-WAN and GE private lines to upgrade to 10GE internet.

EDUCATION

OVERVIEW

The concept of the smart classroom has begun to be widely popularized and applied on campuses. Smart classroom technology is a mode that combines software, hardware, network, teaching equipment, and teaching resources to improve teaching efficiency and quality.

SERVICE CHARACTERISTICS

Typically, a small smart classroom can accommodate 40–50 people and requires two APs. A large classroom has four to six APs. Each AP is configured with 2.5Gbps uplink during peak hours. In addition, there are multiple terminals such as smart whiteboards, three to five cameras, and two sound pickups. Therefore, there are 10–13 APs in each classroom, and 10GE cables are required to connect to the room.

THE IMPACT OF HIGH-PERFORMANCE COMPUTING ON NETWORKS

DCI AND ECI

High-performance computing has the potential to greatly improve the efficiency of AI training and data processing by utilizing distributed computing resources across multiple data centers. To achieve this, it will be essential to explore new solutions such as leveraging future networks to create virtual data centers that connect multiple physical data centers. By interconnecting data centers through high-bandwidth, low-latency, and highly reliable DCI networks we can efficiently share computing resources and facilitate fast data transfer between different data centers. In addition, emerging technologies such as IoT and 5G have increased the amount and complexity of data exchange between central and edge data centers, making efficient network support essential. Innovative technologies such as Segment Routing over IPv6 (SRv6) and SD-WAN can provide flexibility, scalability, agility, security, reliability, and efficiency to meet these demanding requirements.

High-performance computing will have a significant impact on future broadband IP networks and can be broken down into three core use cases: DCI network, ECI network, and networking between data centers and edge data centers.

- **DCI network.** With the rise of large-scale pretrained models, the demand for computing power has increased. However, because of limitations in current network infrastructure, large-scale pretraining models can only be completed within a single data center. This may result in a waste of computing resources. To address this issue, it is essential to explore new solutions that utilize distributed computing resources across multiple data centers and improve AI training efficiency. One effective solution is to leverage future networks to create a virtual data center that connects multiple physical data centers. By interconnecting data centers through high-bandwidth, low-latency, and high-reliability DCI networks, we can efficiently share computing resources and facilitate fast data transfer between different data centers. This will improve AI training performance, increase the utilization rate of computing resources, and reduce overall data processing costs.
- **ECI network.** Because of edge computing's ability to process data locally, east-west traffic has greatly increased at a growth rate of approximately 45% per year. This substantial growth requires the network to have discrete traffic distribution processing capabilities. Traditional

networks have their own system based on transmission and IP network construction, while edge computing access methods are diversified. The network is fragmented and crosses multiple domains, networks, and clouds. As a result, deploying innovative technologies has become essential to meet the demanding requirements of ECI. The ECI network must be able to support high-bandwidth and low-latency communication between edge devices and edge data centers. It must also provide efficient routing and traffic-engineering capabilities to ensure that data is transmitted quickly and reliably. In addition, the ECI network must be able to support dynamic resource allocation and flexible service provisioning to meet the changing needs of edge computing applications. Security is also a critical concern for ECI networks because they must protect sensitive data from potential cyberthreats.

- **Networking between data centers and edge data centers.** The increasing amount of data being exchanged between data centers and edge data centers has made efficient network support more critical. Traditional networks are designed for simple and centralized data processing with low-frequency data exchange between data centers. However, with the rapid development of emerging technologies such as IoT and 5G, the quantity and the complexity of data exchange between data centers and edge data centers have increased significantly. Inefficient networks can lead to delays and packet loss, resulting in degraded performance and a poor user experience. Moreover, the increase in data exchange also means that networks need to provide a higher level of security to protect sensitive data from potential cyberthreats. In summary, the network between central and edge data centers requires efficient and secure communication that can support bidirectional data exchange while protecting sensitive data from cyberthreats.

DATA CENTER NETWORK

According to the IDC quarterly Datacenter Networks Qview (2Q 2022 Release) analysis report, Ethernet is the main technology in current and future data centers, and the proportion of Ethernet in data centers is close to 95%. With the application of technologies such as RDMA in Ethernet, it is predicted that the proportion of Ethernet in data centers will continue to increase in the future. Ethernet will expand to high-performance computing networks and storage networks to form a unified high-performance computing bearer network. Traditional lossy Ethernet cannot meet the high-performance computing power requirements of data centers. To ensure RDMA performance and communication at the network layer, the computing bearer network has high performance requirements, such as high throughput, low latency, and zero packet loss. For applications that require higher computing power, computing power clusters pose new challenges to high-performance data center networks.

New diversified computing power poses new requirements on networks. Next-generation data centers require hyperconverged Ethernet technologies to enable new computing power to cope with new challenges:

- Network-level load-balancing algorithm, releasing computing power
- Device-network collaborative congestion control, optimizing storage computing power
- Fast data-plane convergence, providing high-reliability computing power for distributed databases
- Innovative network architecture, building E/10E-level ultra-large computing cluster
- Service-level assurance, implementing single network bearer in the data center

The bandwidth access of servers is specific to generations. In the general computing field, the server access bandwidth will increase from 10Gbps to 25Gbps in industries such as finance, government, and carrier and to 100Gbps for over-the-top (OTT) services. In the AI computing field, the emergence and rapid development of ChatGPT will bring large-scale investment in AI data centers (DCs). As a high traffic value in the future, it is predicted that the access bandwidth of AI DC servers will increase from 100Gbps to 800Gbps.

In 2022, the Gartner report “Forecast: AI Semiconductors, Worldwide, 2021-2027” predicted that the CAGR of AI chip shipments would be 29%. After ChatGPT was released, Gartner predicted that the CAGR in 2023 would be 42%, an increase of 13 percentage points. There is a strong demand for AI DC expansion in the OTT and financial industries in Asia & Oceania, Europe, and North America. Therefore, we believe that the core scenario of future DCN is AI Fabric DCN.

The rapid growth of the AI DC places three clear requirements on data center networks. First, the computing power of a single data center is rapidly upgraded from 1E to 100E. The parameters of the large model trained by AI grow rapidly to trillions. Elephant flow requires that the network provide an effective throughput rate of over 90%. Third, the RDMA over Converged Ethernet (RoCE) open architecture is widely recognized by finance, carriers, and OTT, which is compatible with various ecosystems and reduces the total cost of ownership.

AI will become a dominant factor from the perspective of DC computing power. It basically includes the following two use cases:

- Large model, mainly developed and operated by the OTT and carrier industry
- Small industry vertical model

To meet the requirements of these AI computing cases, the following key features are needed for the data center network:

- Ultra-large bandwidth supports 400GE accessing.
- One hundred percent throughput: balanced packet switching supports 100% utilization of 100,000 GPU computing power.
- The lossless Ethernet network (RoCE) can access variant computing service and zero packet loss.

EVOLUTION OF REMOTE DIRECT MEMORY ACCESS (RDMA) TO INTER-DC SCENARIOS

RDMA technology may be evolved as a foundation for future inter-DC network technologies because of its ability to achieve high-speed low-latency communication within a DC. RDMA technology allows servers to directly access and write data in the memory of other servers at high speed without time-consuming processing by the operating system or CPU. RDMA networks mainly include three types: InfiniBand, RoCE, and iWARP (RDMA over TCP, internet-wide RDMA protocol). InfiniBand requires dedicated network cards, switches, and routers, resulting in high network construction costs. RoCEv2 is based on UDP to carry RDMA and can be deployed in Layer 3 networks. The RoCE network combined with lossless Ethernet flow control technology solves packet-loss sensitivity and is widely used in high-performance data centers. Currently, RDMA networks can achieve millisecond-level end-to-end latency and bandwidth capacity of 100s of gigabits. However, the current application of RDMA technology is mostly limited to communications within a DC. As inter-DC communication needs increase, there is growing demand for network technologies that can achieve the same level of performance as within a DC. New network technologies need to be developed to meet this demand with RDMA technology serving as a foundation for future inter-DC network technologies because of its ability to achieve high-speed low-latency communication within a DC.

TECHNOLOGY CHARACTERISTICS FOR BB5.5 AND BB6

In the imperative development of a cloud-network convergence, the cloud demands higher network performance, availability, intelligence, adaptability, and security. As a result, service providers are looking for critical capabilities of cloud network solutions to provide their enterprise and broadband consumers with one-hop cloud access, one-network wide connections, one-click fast scheduling, one-fiber multipurpose transport, and a one-stop unified end-to-end security mechanism.

TECHNICAL CHARACTERISTICS FOR RESIDENTIAL MARKETS

Table 2 shows the high-level description of the technical characteristics for the different broadband generations in the case of residential markets. This section concentrates on BB5.5 and BB6 because those are the evolutions toward a broadband network 2023.

TABLE 2: BROADBAND GENERATIONAL ROADMAP FOR THE RESIDENTIAL MARKET

FIXED NETWORK GENERATION	BB4	BB5	BB5.5	BB6 (1)
REFERENCE CHARACTERIZATION	Ultra-fast BB (UFBB)	Gigabit BB (GBB)	10 gigabit BB (10GBB)	Multi-10 gigabit BB (m10GBB)
REFERENCE DOWNSTREAM BANDWIDTH PER USER	100–1,000Mbps	1–5Gbps	5–25Gbps	25–100Gbps
REFERENCE UPSTREAM BANDWIDTH PER USER	50–500Mbps	1–5Gbps	5–25Gbps	25–100Gbps
REFERENCE SERVICES (2)	UHD 4K video	VR video, cloud gaming, smart city	Extended reality, metaverse, digital twins, industrial optical network	tbd
REFERENCE SCENARIOS (3)	FTTH/FTTdp (4)	FTTH/FTTR (4)	FTTR/FTTM/FTTT (5)	O2R, O2M, O2T, fiber sensing (6)
SPECIFICATION TIMELINE REFERENCE	2006	2017	2023	2027 and beyond
REFERENCE BANDWIDTH PER WAVELENGTH AGGREGATION / CORE	100Gbps	200/400Gbps	400/800Gbps	800Gbps/1.6Tbps
AUTONOMOUS NETWORK LEVEL	-	3	4	5
SENSING CAPABILITY	n/a	n/a	Sensing for optimizing O&M	Fiber sensing for various applications, used in computing awareness
GREEN	2× better per bit energy efficiency	5× better per bit energy efficiency	10× better per bit energy efficiency	10× better per bit energy efficiency
RELIABILITY AND LATENCY	99.99%/10ms	99.999%/5ms consistent latency / low jitter	99.999%/1ms (hard guarantees), very low jitter, fast problem detection and response (minutes)	Deterministic reliability / <1ms latency, very fast problem detection and response (seconds)

Notes: (1) BB6 is speculative and is for reference only.
(2) “Reference services” indicates new services enabled by a certain generation. Each new generation supports all services from previous generations.
(3) “Reference scenario” indicates new application scenarios for a certain generation. Each new generations supports and extend the application scenarios of previous generations.
(4) Note that cable technologies can also be used for that scenario.
(5) FTTR = fiber to the room; FTTT = fiber to the thing; FTTM = fiber to the machine
(6) O2R = optics to the room; O2M = optics to the machine; O2T = optics to the thing

SOURCE: WBBA

The BB5.5 generation is addressing the 10 gigabit society, which means each customer gets in the order of 5–25Gbps to their home. The access technology that can provide that symmetric bandwidth is the 50G-PON technology standardized in the ITU. Because of that capacity, specific care needs to be taken for in-home networking, where 10Gbps FTTR systems with Wi-Fi 7 wireless technology are needed to have each room accessible with 10Gbps, therefore increasing the overall user experience in the home including fast handovers of Wi-Fi 7. Since the speed-up in the access and home network is available, the aggregation network and core network need to cope with that capacity and eventually need an upgrade to higher speeds depending on the multiplexing ratio used. In addition, the aggregation and core networks need to be able to provide higher-quality networks including slicing features based on traffic isolation, resource management, and guaranteed performance technologies such as SRv6, slicing, or optical transport network (OTN).

Meeting the demands, the converged 800GE bearer network consists of 50GE to site, 100–200GE access, 400GE and 800GE metro, and backbone in terms of ultra-bandwidth. The aggregation network will become more all-optical so the high quality, flexibility, and high performance can be achieved. The bandwidth per wavelength will increase to be in the order of 400–800Gbps depending on reach. The operational efficiency is increased through going to autonomous network level 4 as defined by TM Forum, which is increasing the level of automation of running BB5.5 networks. A novel feature BB5.5 is using more and more is the sensing capability in fibers for improving network operation using that information in AI-based management algorithms. BB5.5 will increase the energy efficiency per bit of various technologies including all-optical by removing more and more electrical components from the network, using copackaged optics, and having a simpler and flatter network architecture with networkwide energy optimization technologies. Finally, for a set of the novel applications, specifically in the area of immersive experience-oriented applications, low latency and high reliability of the connections are needed to enable a very good experience.

BB6 is the most forward looking of the broadband network aspects addressed in this white paper. Since this is looking quite far into the future, many of those aspects are not well studied and are not standardized either. However, the demands described in the above sections will need technical characteristics for BB6 as defined here. BB6 will need to provide capacity in the multi-10Gbps range. This means all-optical technologies will get closer and closer to the edge such that optical to the room, optical to the machine, and optical to the thing might be needed. The technologies for BB6 are currently in the research phase; the future will show the development. BB6 definitely needs another increase in the energy efficiency per bit, and the networks should operate fully autonomously. The sensing capability can be also used for other applications than operating the optical network for a variety of applications. Finally, the network should allow for fully deterministic performance characteristics, at least for a set of applications with those demands.

TECHNICAL CHARACTERISTICS FOR ENTERPRISE AND VERTICAL INDUSTRY MARKETS

The enterprise and vertical industry markets have different requirements and typically demand more flexibility and a larger range; therefore, in many cases one size does not fit all application demands.

TABLE 3: BROADBAND GENERATIONAL ROADMAP FOR THE ENTERPRISE MARKET

FIXED NETWORK GENERATION	BB4	BB5	BB5.5	BB6 (1)
REFERENCE CHARACTERIZATION	Ultra-fast BB (UFBB)	Gigabit BB (GBB)	Multigigabit BB (mGBB)	Multi-10 gigabit BB (m10GBB)
REFERENCE BANDWIDTH PER SERVICE/ENTERPRISE	≤10Gbps	2Mbps–100Gbps	2Mbps–400Gbps (flexible, on-demand adjustable)	2Mbps–800Gbps (flexible, on-demand adjustable)
REFERENCE BANDWIDTH DATA CENTERS	≤10Gbps	≤100Gbps	≤800Gbps	≤3.2Tbps
REFERENCE SERVICES (2)	Internet access, intranet, VoIP, video-conferencing, file access	Cloud-first, multicloud, and hybrid cloud enterprise applications	DCI, enterprise IT cloudification, industry digitalization, high-performance computing, multicloud computing, HD online meeting, remote office high-speed access	Distributed mobile edge computing AR/VR meeting applications

FIXED NETWORK GENERATION	BB4	BB5	BB5.5	BB6 (1)
SPECIFICATION TIMELINE REFERENCE	2006	2017	2023–25	2027 and beyond
REFERENCE BANDWIDTH AGGREGATION / CORE	100Gbps	200/400Gbps	400/800Gbps	800Gbps/1.6Tbps
AUTONOMOUS NETWORK LEVEL	-	3	4	5
SENSING CAPABILITY	n/a	n/a	Sensing for optimizing O&M application and computing sensing	Fiber sensing for applications, used in computing awareness
GREEN	2× better per bit energy efficiency	5× better per bit energy efficiency	10× better per bit energy efficiency	10× better per bit energy efficiency
RELIABILITY AND LATENCY	99.99%/10ms	99.999%/5ms consistent latency / low jitter	99.999%/1ms (hard guarantees), very low jitter, fast problem detection and response (minutes)	deterministic reliability 99.9999%/<1ms latency, very fast problem detection and response (seconds) (application dependent)

Notes: (1) BB6 is forward looking and therefore is based on best knowledge at the time of writing.
(2) “Reference services” indicates new services enabled by a certain generation. Each new generation supports all services from previous generations.

SOURCE: WBBA

BB5.5 is the multigigabit area for enterprises and vertical industries. The bandwidth is dynamically adjustable from 2Mbps to 400Gbps to cope with the on-demand model of cloud technologies, which needs to be reflected in the networking for accessing the cloud. The data center infrastructure for the cloud needs high networking speed because of the evolution of the workload toward AI-based algorithms applied to many different applications running in the data centers. Enterprise access networks are of various technologies depending on the level of guarantees, quality, and performance that enterprise customers require for their networking needs. The technologies include PON, OTN, and Ethernet-based access. The FTTR or Passive Optical LAN (POL) technologies are interesting for enterprises and depend on the size of the network deployment. They are even more so for some vertical industries for low-energy, high-performance networking on-premises, including very low latency for machine and robot control. The aggregation and core networks have to cope with the dynamic adjustability and capacity needed for the demands on the enterprises. The other characteristics in terms of automation, energy efficiency, reliability, latency, and sensing refer to the section above; they are the same for residential and enterprise segments, except that enterprises may need a larger range and more flexibility to get what they require.

As one of the advanced end-to-end feature of BB5.5, 800GE digital private network enables the carrier to provide additional digital services on top of connectivity. Industry users can choose either a private line or a private network and add the managed digital services such as managed LAN and wireless LAN (WLAN) services, managed security, managed DCN, and managed cloud, which may be based on SRv6, slicing, and so on. Digital private network does not just help carriers to unleash the power of cloud-network synergy; it also makes the life of vertical industry users much easier since both connectivity and cloud services can be settled down by one stop.

Cloud-based campus services and wireless access have become a trend. There is a clear generational change in Wi-Fi. Wi-Fi 7/8 will gradually replace Wi-Fi 5 and Wi-Fi 6. The number of GE ports on wired switches will reach a 24-year peak value, and the shipment of 10GE ports will continue to increase.

Campuses will embrace 10GE campus networks, including three 10GE upgrades. Office networks will be upgraded from GE to 10GE; production networks will be upgraded from 10GE to 100GE; and branch networks will be upgraded from GE to 10GE. To meet the requirements of the preceding 10GE campus case, the campus network requires the following key features:

- Ultra-broadband wireless access: next-generation wireless access technologies such as WiFi7 / WiFi8 support 10Gps access
- High-density 10GE wired bearer: high-density 10GE switches
- Ultimate experience and zero audio and video loss: identify audio and video services, ensure audio and video quality through end-to-end slicing, and locate faults within minutes during flow detection

For BB6 in the enterprise space, the expectation is that the current trends in terms of cloudification and digitalization are further increasing the need for better performance in any of the dimensions. That also means the network architecture moves further toward optical to everywhere, and more and more into the enterprise premises.

TECHNICAL STANDARDS FOR BB5.5 AND BB6

The broadband generations define holistic network system-level characteristics demanded by customers and applications. Broadband technologies need to be able to achieve those characteristics. The different technologies are defined at various standards forums, a short overview of which follows:

- **IETF – The Internet Engineering Task Force.** The IETF defines not only the internet protocol suite but also management protocols and data modeling languages. SRv6 and YANG data models at the service layer, for example, L3SM (L3VPN Service Model), and network layer, for example, L3NM (L3 VPN Network Model), are important enabling technologies developed by IETF for network automation.
- **ETSI ISG F5G – The Fifth Generation Fixed Network Group (F5G and F5G Advanced).** The F5G community describes a large set of use cases for F5G (similar to BB5) and F5G Advanced (similar to BB5.5). Based on the use cases, technology requirements and eventual gaps are shown. Finally, an overall holistic end-to-end network architecture is defined using many of the technologies defined in the forums below.
- **ITU-T SG15 – various baseline technologies.** SG15 has several subgroups defining various optical communication technologies in the different end-to-end segments. On aggregation network and transmission technologies include OTN with its evolution (higher speed and sub-1G), management of transmission systems, and synchronization. In metro area network, fine-grain metro transport network (G.fgMTN) is launched for carrying lower-rate premium packet service. In the access network segment, several PON generations and bidirectional Ethernet access technologies are defined. In the home/customer premises network segment, FTTR and Li-Fi technologies are defined.
- **BBF – Broadband Forum.** The BBF defines various aspects of access networks including the home router management, PON management data models, and wireless and wireline convergence.
- **IEEE – Ethernet and Wi-Fi.** IEEE defines the basic Ethernet and Wi-Fi technologies (e.g., Wi-Fi 7/8) used in broadband networks. This is also very important for the DCN aspects of broadband. IEEE P802.3df Task Force is defining an eight-lane interface supporting 800Gbps Ethernet, and P802.3dj Task Force is working on 800Gbps and 1.6Tbps Ethernet with more advanced 200G/lane optical and electrical technology and coherent optics. IEEE802.11be Task Force (focused on Wi-Fi 7) is defining the air interface protocol that supports the peak rate of 39.6Gbps and uses various technologies such as 4KQAM high-order modulation and dual-link transmission. IEEE802.11bn Task Force will define more advanced air interface protocols that operate in the 1–7.125 GHz band to improve throughput, latency, and energy consumption.
- **ETSI ISG ENI & ZSM.** The ETSI Industry Specification Group on Experiential Networked Intelligence focuses on improving the operator experience, adding closed-loop artificial intelligence mechanisms based on context-aware, metadata-driven policies to quickly recognize and incorporate new and changed knowledge and hence make actionable decisions. The ETSI ZSM group was formed with the goal to accelerate the definition of the end-to-end service management architecture, spanning both legacy and virtualized network infrastructure, to enable automatic execution of operational processes and tasks.

THE NEED FOR SYNCHRONIZATION AND ALIGNMENT OF STANDARDS

As shown above, because of the various organizations and different set of technologies, it is difficult to maintain an overview. Since WBBA is looking at the broadband network holistically, the different technologies should be synchronized in their development and lifecycle, and they should easily interact with each other in an end-to-end communication network. Therefore, a certain degree of alignment of the technical standards and also of timing and roadmaps will ease the deployment of future broadband networks. This is one motivation for WBBA to work on roadmapping of broadband networks and have industry consensus to the largest extent possible on the level of the roadmap and network demands.

MIGRATION TO BB5.5 AND BB6

The migration from BB5 to BB5.5 is supposed to be straightforward since there is no change in the network architecture expected. BB5.5 is basically improving the performance and functionality along various dimensions for better services to the customer taking the variety of applications into account.

COPPER PHASEOUT

From the broadband generation BB5 onward, the technology is all fiber, so at some point the discussion on copper phaseout needs to start. The prerequisite for the phaseout is naturally full fiber deployment in a region. The next step is to stop selling copper-based subscriptions and services, developing alternative service offerings in fiber technologies (e.g., full PSTN migration to VoIP, machine-to-machine communication using PSTN to IP/fiber-based solutions). Finally, copper networks can be dismantled. In all the steps, a well-handled customer journey is very important so as not to lose subscriptions and market image.

Only the phaseout of copper will show the full business benefit of fiber in the form of smaller equipment footprints in central offices and central office consolidation thanks to the longer reach of fiber technologies. Copper phaseout is needed to reduce energy usage, which is only possible if a copper and a fiber network are not run in parallel.

APPENDIX

FURTHER READING

Gartner (April 2003) “Forecast: AI Semiconductors, Worldwide, 2021-2027,” Gartner Research, available at www.gartner.com/en/documents/4248199

Plume, (2023) *Plume IQ Yearbook 2022*, available at https://content.plume.com/v/plume-iq-yearbook-2022

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