OMDIA

The research on the trends of Data Communication Network for 2030

Network Evolution towards 5.5G Era (Net5.5G)

Contents

1.0 The evolution of the network and advances in digital technology

The trend of a full IP and intelligent data communication network is irresistible

Data communication networks, abbreviated as networks (including campus networks, wide area networks [WAN], data center networks, etc.), represent telecommunication and enterprise networks' logical evolution. The birth and initiation of the data communication network is represented by the internet. Data communication networks, essentially evolving from TCP/IP, are responsible for intelligently routing data over geographically distributed long distances and limited domains. Technologies related to data communication networking are growing faster and have various requirements in connecting the physical and virtual worlds of the digital era. The essence of data communication networks is the underlying internet infrastructure, which is the leading candidate for the modern world's digital convergence. The data communication network will play an essential role in interlacing and digitizing the zettabytes of data connecting billions of hundreds of connected things and objects in the future—but for some reason remains eclipsed and unattended due to the focus on other digital technologies.

By 2030, ubiquitous remote sensing technologies, wired and wireless 10GE broadband, inclusive AI, fast computing, and industry-specific applications will be used to deploy digital infrastructure. These technological advancements are growing quickly, but the most important question yet to be answered is: Will the existing ICT data communication networks be intelligent enough to handle the vast amount of data in the industrial revolution and the new chapter of the internet known as the "metaverse?"

Looking ahead to developments in the industrial internet era (such as metaverse AI and computing power) over the next 10 years, internet infrastructure will see many challenges around deterministic networking experiences, multicloud interconnections, ubiquitous trustworthiness, intelligent operations, and predictive operations and maintenance.

Communication networks have rapidly developed in the last decade, with more sophistication expected in the upcoming digital era of the industrial revolution. The emergence of new, robust, powerful, and diversified use cases and digital scenarios fully embraces an intelligent world, driving massive growth of data communication networks.

The evolution of the network and emerging innovation

Since its experimental birth and evolutionary development 50 years ago, the network has connected various applications and terminals openly and inclusively. Applications and devices drive the expansion and development of the network. The true essence of the data communication network is the periodic evolution of network infrastructure.

Understanding the underlying logic of the network's evolutionary periods and historical developments is necessary to understand the law of future digital network modernization of fixed data communications networks.

ARPANET experimental networks, internet before commercialization: 1990

This era marked a revolution in the history of the communications industry, allowing the public to share and exchange limited information by sitting at distant locations with a maximum of 1G speed.

Evolutionary highlights of this era were:

- First, the experimental non-commercialized Advanced Research Projects Agency Network

(ARPANET) was introduced; it originated in the US in the last century and has since evolved into the National Science Foundation Network (NSFNET). Communication and data exchanges were restricted and only allowed to research organizations and governmental departments for military use.

- TCP/IP became ARPANET's new standard and unified IP stack that allows the linking and connecting of computers for information exchange, effectively known as the Intergalactic Computer Network. In this era of public use, the internet was mainly for simple information and low-speed data transfers.
- The first-generation internet was unreliable, used IPv4, had no quality of service (QoS), nor guaranteed user experiences.
- Later, more technological inventions and sophistication allowed computer users to connect directly to their phone lines to create a personal network that people had never experienced before.
- Modems enabling network communication were invented in different shapes and sizes, pushing communication into bits per second and beyond. Hence, an era of basic broadband with a maximum speed of 1G was also remembered as Net1G services.
- Core applications of that era were mainly plain emails and limited-sized file transfer exchanges.

Commercialization and the explosive use of the WWW: 1990–2000

The NSF lifted its complete ban on internet commercialization, unleashing the real hidden value of the internet and ushering in a golden decade of explosive broadband development. As a result, the internet has gradually become the preferred channel for people to obtain information quickly.

Noticeable highlights of this era were as follows:

- The 56K modems gained global momentum, became one of the biggest technological breakthroughs, and gained traction owing to affordable prices and comparatively better speed.
- The World Wide Web (WWW) started, giving people freedom to run small businesses and communicate online. The invention of the WWW laid the foundation for developing internet applications and revolutionizing the broadband ecosystem.
- Local area networks (LAN) and WAN were built to meet small consumer and business demands, offering better interactive web browsing experiences and visual imageries.
- The emergence of free browsers, in the form of Internet Explorer, further promoted internet applications to thousands of households, and people could get connected. In addition, big companies like Yahoo and ask.com gained popularity.
- The typical Ethernet technology was 802.3u and the bandwidth could reach 100Mbps; the typical Wi-Fi technology was 802.11.
- At the end of the 1990s, connected hosts exceeded 40 million, and internet users exceeded 200 million.
- Now, internet web and search portals mark the era of connectivity.

Social media, 3GPP 3G wireless internet and IP multi-service bearer: 2000–10

Users' demands for internet applications evolved from a focus on information acquisition to social networks and mobile internet.

Noticeable highlights were:

- Fixed internet broadband as a mainstream technology became a necessity of life owing to convenience.
- Wireless 3GPP released revolutionary 3G standards that marked an era of 3G voice and internet data services.
- The internet started appearing on cell phone screens owing to the ease of access.

Application services like wide-area wireless voice, mobile internet (a fascinating feature), video calling, and on-the-go TV gained immense popularity.

- Wireless 3GPP standards specified all core network interfaces would be IP-based, allowing TCP/IP in the mobile internet field, marking the arrival of the true IP-based telecom network development era.
- Data communication networks enabled wireless backhauling projects to meet the standards of a 3G network for supporting and connecting wireless data traffic to its respective core networks.
- Communications service providers (CSPs) started bundling fixed and mobile data services and offered convergence services to VIP premium users.
- Another fast-growing application was point-to-point Layer 2 transport, which could be used either as a means of transporting customer Ethernet traffic across a wide area or as an emulation of ATM or Frame Relay services. The typical Wi-Fi technologies were 802.11n/ac.

Short video, 3GPP 4G wireless data, and the mobile internet era: 2010–20

Noticeable innovations and developments in this era continued from the previous generation but with additional service sophistication and digital innovations.

- 3GPP launched wireless 4G LTE networks for better mobile internet speeds, and the 4G standard supported mobile internet speeds from 100Mbps to 1Gbps.
- The number of mobile devices connected to the internet exceeded that of wired devices in 2011 because of mobility.
- 4G standards set peak speeds at 100Mpbs for high-mobility communication and 1Gbps for low-mobility communication.
- Home broadband became popular and a rival technology to wireless 4G in terms of faster and more reliable connection and speed factors.
- Wi-Fi at homes got popular for connecting various house terminals for internet connectivity.
- Various handheld devices (the iPhone, Android, iPad, and more) with large screen displays saw tremendous development, started launching in the market, and sparked various interactive mobile internet applications.
- Demand gradually grew for applications including short videos, videoconferencing, and large file transfers and for always-on free internet data connectivity.
- IP QoS and multicasting techniques gained popularity and saw advancements.
- IEEE released the 40GE/100GE Ethernet transmission standard, which was widely used in all network layer transmission. Most customers chose to directly upgrade from 10Gbps Ethernet to 100Gbps Ethernet; the typical Wi-Fi technologies were 802.11n/ac.

Cloud computing, 3GPP wireless 5G data, industry digitization, and 5G: 2020–25

In this internet age, speed, latency, and deterministic experiences are the competition grounds and are in high demand to meet new diversified digital service requirements. This era is categorized as 5G, where cloud computing and enterprise digitalization started and are supporting the rapid development of general-purpose cloud computing and cloud-based applications.

- 5G mobile communication has created new opportunities for humans and machines to communicate (the IoT).
- The target network infrastructure requires data communications bearer network modernization and sophistication. IP networks are established as the backbone and are imperative for supporting the 5G wireless mobile internet traffic backhauling to core networks.
- Cloud computing started gaining momentum, and network as a service has become a new trend.
- The era of initiating enterprises to move to the cloud has started.

- AI triggers basic fixed network automation and network orchestrations.
- Smart cities, smart homes, IoT, fast mobile internet, and fast home broadband-based applications started and demand new stringent requirements.

Metaverse, Industry 4.0, full-blown AI, and 3GPP 5G Advanced (5.5G): 2025–30

This era marks the future of the network, where the historical mission of network development is shifting from realizing connectivity of the physical world to the digitalization of vertical industries and AI-enabled cloud computing.

Therefore, intelligent, high-performance data communications bearer networks will be imperative and the backbone to connect industrial production networks, metaverse-enabled AR/VR realities, AI-enabled industrial digitalization, distributed computing powers, and the intelligent internet of everything.

The noticeable achievements expected in this era are as follows:

- Wireless 5G standards were set in 3GPP Release 18, focusing on 5G Advanced (5.5G) capabilities and demanding a new generation of data communication networks.
- Unlocking a next-generation end-to-end (E2E) intelligent IP network is imperative for success in the 5.5G era.
- Wi-Fi 7, ubiquitous computing power innovation, high-end resilient data centers, and greener networks will be the way forward.
- There will be metaverse and extended reality (XR) applications and the automation of vertical industry production systems. Ultra-low latency is key for applications such as driverless cars, remote control management of factory production, and robotic systems.
- Diversified and distributed computing resources will be mainstream for sensory communication enabling immersive XR and human augmentation.
- Industry digitalization will gain more traction with smart manufacturing, and the Industrial internet of things (IIoT) will be mainstream.
- VR convergence in the form of the metaverse will start a new chapter of the internet; it will be a critical driver in building holographic interconnections between the physical and virtual worlds.

In short, it is well-established that the growth and evolution of the internet require changes in the underlying IP transport networks.

In Chapter 2 of this whitepaper, Omdia conducted detailed industry executive interviews, analyzing the technological landscape of the future enterprise and service requirements in 2030.

In addition, have a detailed look at the catalytic forces behind the intergeneration leap and the necessary technological advancements to build an intelligent data communication network in Chapter 3.

2.0 Looking into 2030: The possibilities for commercial applications and impact on network requirements

Consumer and enterprise experiences of 2030

Consumer video, metaverse, and the drive for bandwidth in 2030

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 or are integrated with our bodies. By 2030, there will be 13.7 million new consumer devices connected daily, with a total of over 9 billion consumer mobile connections and 33 billion consumer IoT devices.

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 using AR or fully immersive 3D experiences—through 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.

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 everything they do in the physical world in the digital 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 needing 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.

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 Web 3.0 technology will enable new business models, meaning that resources are less owned, but recycled, re-used and shared—bringing both economic benefits to the consumer as well as reducing environmental impacts.

Today, video accounts for approximately 80% of all internet traffic and is the leading driver of consumer broadband speeds. As the world moves toward 2030, this demand will only increase exponentially as video services transition to high-quality 8K video, needing between 80Mbps to 100Mbps per channel, and consumers adopt advanced VR applications (such as Free-Viewpoint video), which could see demand for up to 5Gbps per stream. The continued need for higher-bandwidth consumer services is a given.

However, greater speed is not the only future network requirement. Today, most video traffic is streamed. With streamed video applications, network characteristics such as latency and jitter are essential. Yet, using techniques such as buffering, adaptive bitrate controls, and dynamic optimization mitigates at least some fluctuations in network performance without significantly affecting the end-user experience.

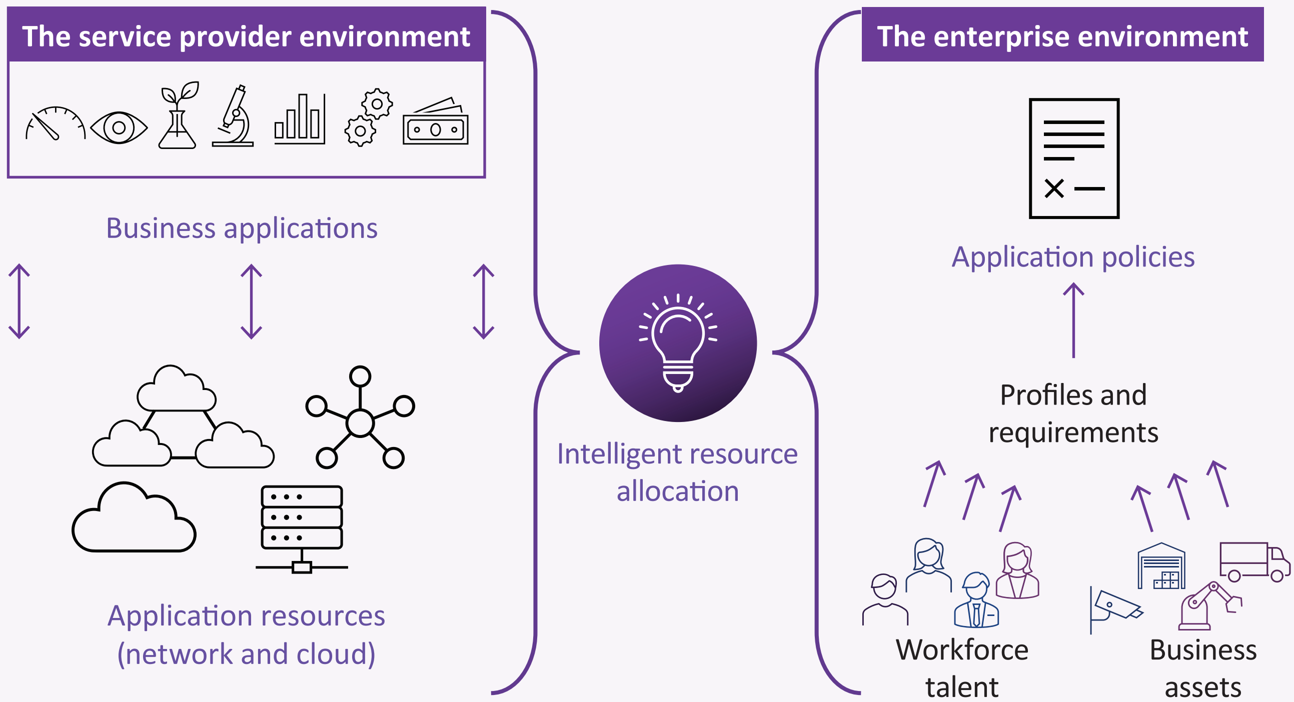
However, as we move to the metaverse, applications will be far more interactive. Any glitch in network performance would be more harmful to the end-user experience. Therefore, the quality of the user experience will depend on network characteristics such as latency, jitter, consistency, and reliability, which are as important as bandwidth. By 2030, the World Broadband Association predicts that broadband access networks in advanced countries will need to achieve reliability of greater than 99.999%, less than 1ms latency, and extremely low jitter.

Not all metaverse applications will require such high-performance networks, and metrics such as speed, reliability, latency, and jitter alone do not fully reflect the end-user experience at the application level. Therefore, the critical technology developments for future networks are the capability to understand each application's traffic flow; how factors such as reliability, latency, and consistency will affect the final outcome; and setting network priority at an application level to ensure delivery of the required quality of experience.

The application-driven enterprise in 2030

For businesses in 2030, cloud services will have been mainstream for over two decades. Enterprise workloads have shifted almost exclusively to the cloud—or rather, a collection of intelligent, interconnected clouds—that adapt to changing applications loads, user and device needs, available compute resources, and network traffic conditions. The underlying resources align to meet requirements that are application-specific and set by the business for acceptable response intervals and work experiences. Business policies define acceptable outcomes. **Figure 1** shows the model for how people, devices, applications, and supporting resources coordinate intelligently to support business outcomes.

Figure 1: Network, cloud, and applications are coordinated intelligently to business requirements



Source: Omdia

Enterprises still maintain technology departments in 2030 that manage IT and operational technology (OT). The department's role is as a gatekeeper and developer of ideas, exploring the potential for new technology to benefit the business. The technology department assesses new applications, platforms, and solutions in a digital twin environment. The digital environment 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 configuration and adjust interfaces and adapters. They can then test how the configured solution works with existing equipment and software in the twin environment. When 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 workers' 2030 toolkit includes: MR for complex human visualization and response; AI and machine learning (ML) 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.

Below are examples of how new technology has driven intelligence and efficiency for key enterprise functions in 2030. New capabilities will improve commercial transportation on public roads, promote safety and smooth operations on private worksites and large campuses, help knowledge workers make better decisions through data visualization and analytics, and tag application environments and rich data to individuals and organizations for better outcomes.

Smart transportation – The network-connected vehicle

By 2030, public transportation infrastructure and vehicles will have become even more intelligent. Smart highways and autonomous vehicles will reduce travel times, accident occurrences, and energy usage. Many personal vehicles will not be fully autonomous, but 2.8 billion vehicles will be connected, most of them (nearly 2 billion vehicles) for commercial use. Connected vehicles augment existing vehicle intelligence that assesses conditions and includes operator assistance to help make public roads safer.

Video monitoring solutions for commercial vehicle operators have been in place for decades. By 2030, multiple mounted vehicle cameras will stream internal- and external-facing video footage. These streams will run through cognitive analytics to assist the driver. Cameras will also monitor for security and help the business avoid liability. Vehicle cameras will monitor inventory and show the driver is not distracted from the road.

If a vehicle has trouble on the road or a driver experiences issues, cognitive analytics will identify the problem and can address it immediately. In 2030, there will be far fewer traffic incidents. However, when something goes wrong, video and telemetry data may help the commercial driver (and, therefore, the business) identify the root cause of the problem.

Smart worksites – Productivity with precise sensing

In 2030, controlled site environments will be highly automated. Lights-out warehouses will be the norm, housing autonomous guided vehicles (AGVs). Forklifts and pallet jacks will store and retrieve inventory quickly and precisely, while conveyors sort and process input and output. The fully automated warehouse will be more efficient, accurate, and orderly; it can store more products on-site because it no longer needs spare floor space to accommodate human worker foot traffic.

In the same way that video streaming is key for smart commercial transportation on public roads, video streaming and cognitive analytics are central to worksite safety, compliance, and security. Video capture is a decades-old tool for enforcing safety regulations and security surveillance. In 2030, 11.5 billion security and site automation devices will be in play across residential and commercial applications. Many of these will be connected video cameras that keep operations running safely and smoothly.

Video capture on worksites will be paired with cognitive processing and AI or analytics to play a proactive role in worker compliance, asset tracking, security alerts, and issuing other alarms. For example, cameras can ensure workers wear goggles, helmets, and vests properly and follow company safety policies. Through geofencing, video works with tools such as RFID to track materials, equipment, and the locations of authorized workers on site. It also detects and responds to unauthorized or unknown persons that enter unsafe or restricted areas.

While some AGVs run repetitive business operations, other autonomous and semi-autonomous vehicles deployed for worksites are flexible and task-oriented. Air and ground drones use cameras and telemetry, including location tracking, to patrol and investigate changes detected in field conditions for large sites. Drones can access hazardous or hard-to-reach places within minutes, providing detailed visual data and analysis. These automated vehicles complement telemetry systems in sites, such as large refineries, power plants, public works projects, construction zones, and secured facilities.

Visualizing and manipulating data for human perception

In 2030, the collective group of MR devices (AR, VR, and XR) will be mainstream tools in wide use by knowledge workers. These tools, coupled with kinesthetic controllers and haptic feedback, can help workers visualize, organize, and manipulate large datasets to gain new business insights.

The impact of MR spans across worker roles and industries. Enterprises ingest a constant torrent of data that is analyzed in real-time for immediate response. Knowledge workers look for ways to further combine and leverage these data sources. They turn sources of information into intelligence that helps the business make better decisions. Some examples are as follows:

- In manufacturing, visualizing the factory floor to make operations more efficient; also, to conceptualize, prototype, and iterate new designs before creating physical models
- In agriculture, assessing soil conditions to decide when and where to irrigate or apply chemicals
- In financial services, running analytics to project scenarios for future market performance
- In healthcare, conducting remote robotic procedures, likely with AI agent assistance
- In mining and energy, visualizing physical spaces and subterranean formations to understand the earth's strata and plan how to optimize extraction
- In retail, helping customers experience a new lifestyle product or service before making a purchase

In 2030, AR will be mainstream for industries that work with large and expensive specialized equipment. A specialty subject matter expert at headquarters and on-site field technician can don AR headsets with video to walk through maintenance, repair, or upgrades of sophisticated equipment together. The site technician might initially work with an intelligent agent that applies cognitive analytics to the live video stream. The agent will provide visual cues to walk the site technician through a procedure step-by-step. The agent will then assess and confirm whether the technician completes each task step correctly.

Smart services – Fast, accurate, and personalized care

By 2030, the delivery of services will be accelerated, personalized, and yield better outcomes. This includes improvements in business and professional services, retail, education, the healthcare sector, and public sector services. In the healthcare sector alone, more than 5 billion connected devices will be in play in 2030, a mix of consumer medical and clinical care gear to monitor and improve health outcomes.

Organizations have kept electronic records for decades. By 2030, the information collected will be comprehensive and correlated well enough to understand and work with constituents individually, whether other businesses, customers, students, patients, or citizens. The data is tagged to the individual, and organizations must ensure that personal and sensitive data is protected and privacy preserved.

This rich correlated data on individuals can help people, even save lives. For example, in healthcare, electronic medical records with rich media can include information about prescribed pharmaceuticals; they can attach high-resolution imaging files, data on past medical visits, and videos of past surgical procedures. Intelligent analysis can help guide medical staff on the proper course of action if the discharged patient must return to the hospital.

Sometimes, rich data just makes for better personal outcomes. In 2030, competitive retailers will need to understand their client base to encourage a steady stream of return customers. Based on a regular buyer's past purchase habits, retailers can suggest what other products or services might best fit their interest. For prospective retail customers, MR replaces digital signage as a way to engage with and experience new products and services. A virtual retail floor can showcase new products under consideration, together with past purchases, helping the customer make more informed decisions that suit their personal preferences.

In the education sector, remote learning programs have long been in the mix. In 2020, the COVID-19 pandemic exposed bumps in adopting tele-education, but it also showed what was possible. Universities in 2030 will have both a physical campus and extended virtual spaces. Students can interact with each other and educators in the social metaverse, collaborating on projects and learning from anywhere.

For business services, the entire technology kit of 2030 comes together for better outcomes. Business and professional services rely on the skills of their talent to succeed; this sector thrives on empowering workers to do their jobs better and more efficiently. Collaboration, analytics and data visualization tools and access to data sources and distribution (including the metaverse) will ultimately benefit the business. AI agents will assist workers and may offload some rote tasks, allowing talent to focus on higher-value needs for the business.

Network requirements in 2030

By mapping the applications needs of the future against network requirements, some common threads emerge. Service provider networks of 2030 will need to carry 10x the bandwidth they did 10 years earlier. This hunger for capacity comes from far more connected devices and higher bandwidth per device.

Campus networks: Wireless, video, and the metaverse

Many smart worksites in 2030 will still engage with traditional physical materials and assets, but they will have an information dimension. Worksites will depend on live, real-time video that works in tandem with rich telemetry data. Real-time video streams have substantial bandwidth requirements; a highly compressed, low-quality video stream can work at 1Mbps. Many cameras coupled with cognitive analytics will need an eye for detail. Up to 25Mbps HD video and up to 100Mbps for 8K video streams will be more realistic. Telemetry can also generate very large volumes of data. For example, distributed acoustic sensing is used by the energy industry to monitor seismic activity; such a system can generate 10TB of data each day.

Large worksites in 2030 will have many dozens of cameras generating real-time video streams. Some are wired in permanent locations or embedded in static machinery. Some are wireless, mounted in vehicles, or worn by workers. Some cameras are wireless but stationary, occasionally moved as the worksite changes. The bandwidth of each captured video stream will vary based on what events and objectives it is assigned to monitor and analyze. The average large worksite in 2030 easily generates multi-Gigabit streams of machine-generated traffic. The data is collected, analyzed, correlated, and used to initiate responses in real time.

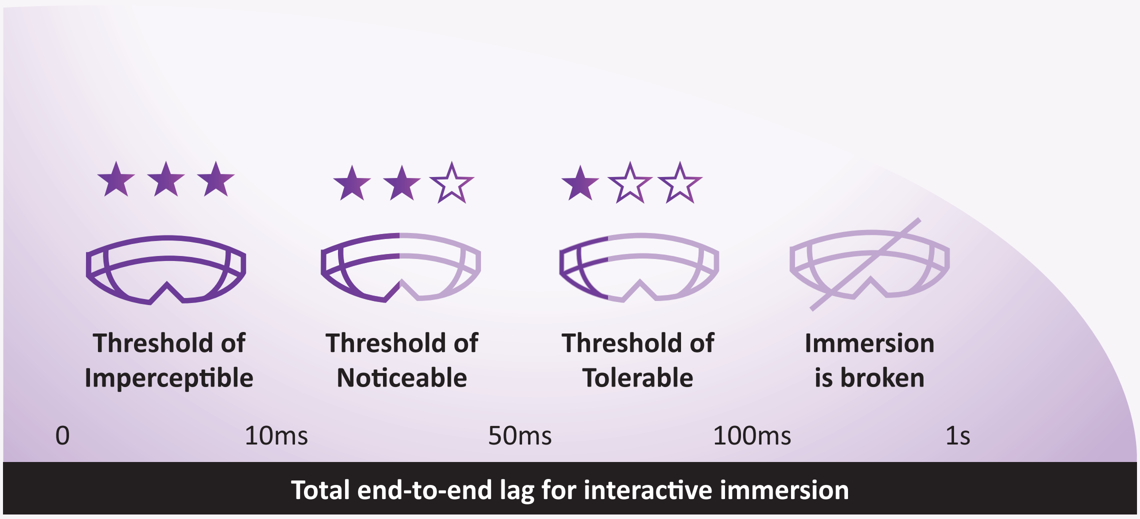
Whether on-site or remote, the knowledge workers of 2030 will occasionally need to perform real-time, interactive data modeling and analysis. This task can be extremely computing- and bandwidth-intensive. When it comes to visualizing and analyzing large datasets, MR requirements are similar to other types of streaming video: up to 25Mbps or up to 100Mbps for video data streamed to the device, plus additional bandwidth for other sensory feedback. The network and cloud resources needed to power the application behind the scenes may be extremely demanding.

Immersive and fully interactive metaverse experiences require a great deal of bandwidth (1Gbps or more) to simulate the continuity of real-life experiences. Depending on the type of business and tools made available to the workforce, the future workplace may need a base between 100Mbps and 1Gbps per knowledge worker on site, possibly much more.

Workers in the metaverse will not need to move around the site to collaborate, but workers not tied to the metaverse will need a performance profile that follows them around the site. Ideally, this worker profile also accompanies the worker to the home or in the field, wherever they may work. In the workplace, high-performance wireless networks will support in-person meetings and project collaboration. Besides planning bandwidth for each knowledge worker, the business needs to calculate fixed bandwidth to connect site-hosted servers to the global distributed cloud.

Adequate capacity is one dimension, but another important consideration is minimum E2E performance. For any real-time human interface, the quality of experience is ideal with E2E lag below 10–15ms, acceptable when lag is below 50–60ms, and tolerable when lag is up to 100ms (see **Figure 2**).

Figure 2: The effect on lag on human perception and the immersive user experience

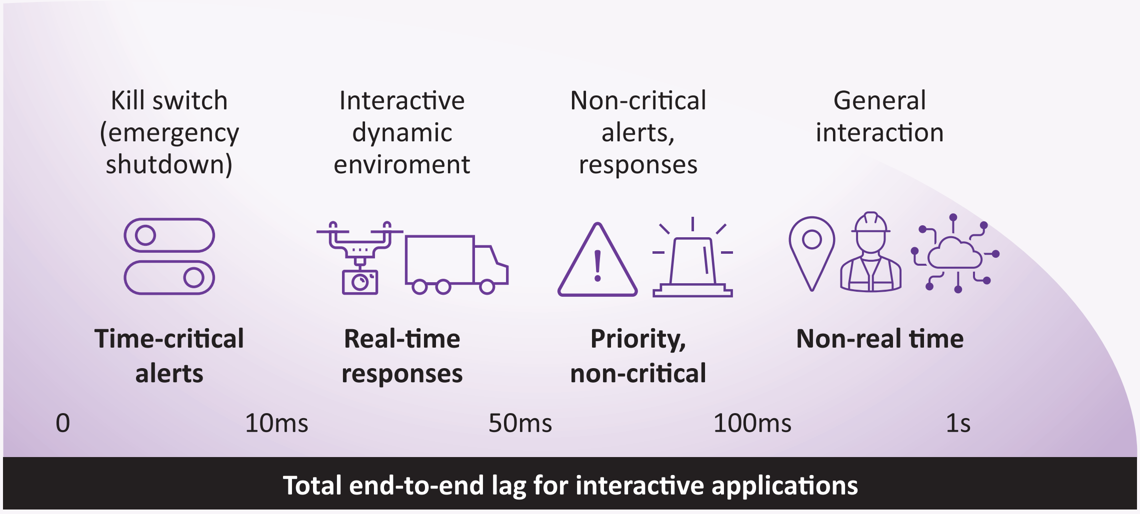


Source: Omdia

For real-time machine telemetry and cognitive video processing, tolerances vary based on application. Sub-1ms response times are sometimes vital, such as in high-speed manufacturing processes and critical safety sensors. A simple example is a shutoff toggle that prevents equipment damage or worker injury. AGVs that operate in dynamic, dangerous environments ideally need lag under 10ms to respond to unexpected events. Other types of video surveillance are not as rigorous. Some priority triggers might need response times under 100ms (for example, a non-critical machine alert). Others could take a full second or more (e.g., reminding a worker to wear safety gear properly or a location update for equipment).

Figure 3 shows some examples of acceptable performance ranges for key devices and functions. The applications themselves inform network and cloud resources of their full performance requirements. Based on that information, the campus network organizes itself to prioritize wireless and wireline traffic. The higher performance needs will be supported by new generations of Wi-Fi, able to handle many simultaneous multi-Gigabit bandwidth streams.

Figure 3: Performance and machine requirements for sample applications



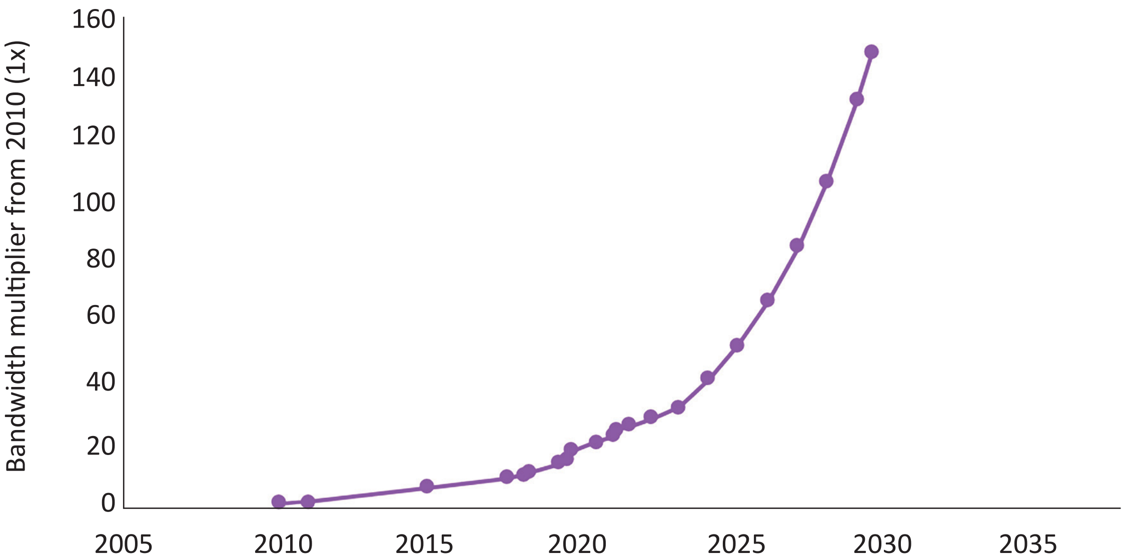
WAN, diversified computing, and multicloud interconnection

The network and cloud of 2030 (many networks and clouds) will act as a coordinated whole. Requirements are set by the enterprise's business policies, and policies are set by the applications. When an element in cloud and computing resources approaches a performance ceiling, intelligent agents notify the affected provider that additional hardware and resources are needed to maintain customers' guaranteed service levels.

In 2030, network and cloud resources from service providers will be tightly woven together in a high-performance, distributed, and fully interconnected fabric. Cloud connectivity had already been splintering into multicloud environments a decade ago. For businesses in 2030, private, hybrid, and public clouds, hosted platforms, and hosted software as a service will work as a unified whole.

The growing appetite for carrier bandwidth has remained near steady for the past 20 years. By 2030, the hunger for network traffic worldwide will moderate, but only slightly. Many leading providers experienced a near 30% compound annual growth rate (CAGR) in traffic in 2010–20, but by 2030, traffic demand will grow well over 20% each year (see **Figure 4**). To 2030 and beyond, traffic growth will continue to be brisk, reaching 150x the net traffic that carriers transported 20 years prior and about 10x the traffic growth between 2020 and 2030.

Figure 4: In 2030, providers will carry about 150x the traffic they did in 2010

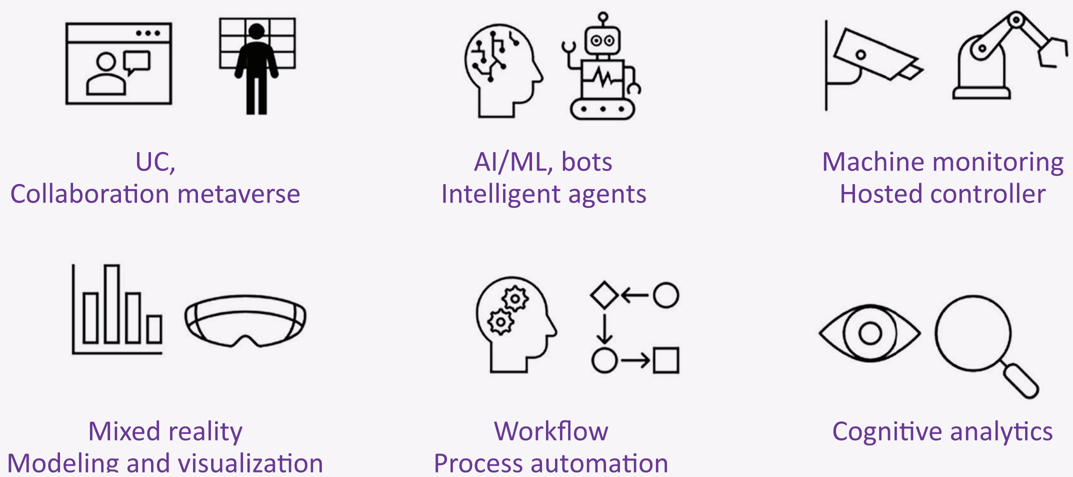


Enterprises will continue to increase the traffic they push onto networks in 2030. The inputs will comprise a mix of machine-generated information and human collaboration. Enterprises need to decide how best to handle the massive volumes of data collected by their operations. They will choose what sources to keep fully intact and for how long; what sources to concentrate or truncate, storing only some parameters; when data is no longer considered useful; and how to dispose of it. The goal is for the business to curate its data streams: which to use for immediate decision-making only and which to keep for future analysis; which to retain for a short time and which to hold long-term; and which to keep only slices of the original data and which to keep fully intact for future granular analysis.

Knowledge workers will need access to these very large datasets so that manual operators and intelligent agents can manipulate them. Workers can compare the data sources to search for patterns and correlations. Where the data is stored should not matter. To securely access, visualize, and combine different data sources regardless of where they are stored (and doing this in real time) will require extremely high-performance computing and storage tied to ultra-broadband and highly elastic bandwidth. Coordinating remote datasets in real-time will require the low latency and lossless transfers afforded by deterministic networks. The entire network/compute fabric will need to be self-driving to organize and meet these requirements.

Back in 2020, the shift of applications to the cloud was already well underway. Organizations migrated their existing applications to the cloud and added new digital, cloud-native applications. Through 2030, the core categories of applications will remain about the same. Application bandwidth and performance requirements have continued to increase. **Figure 5** shows key demanding, mainstream enterprise applications in the cloud by category. Each of these applications has evolved over the years to push performance requirements higher.

Figure 5: Sample mainstream enterprise applications where evolution has grown bandwidth and performance requirements



Source: Omdia Enterprise IT Services Insights, n=310

Data center networks: Growing to a huge scale

In 2030, the data center will be part of the WAN fabric, whether set up strictly as a private cloud or extends to public cloud infrastructure. The storage and compute resources, and the network attachments to keep up with the demand to manipulate and transfer data, are truly massive. Network bandwidth has grown 10x over the last 10 years. Data centers have needed to scale by 10x to keep up with traffic. They had to scale by another 10x to meet vastly increased remote processing demands. The data center has also reduced latency by up to 10x to support critical applications where the entire round-trip transaction is measured in microseconds.

To keep up with performance demands, data centers must have fully coordinated network and compute elements. Data centers in 2030 will carry forward concepts such as RDMA over converged Ethernet (RoCE), taking advantage of connecting to a large-scale parallel, non-blocking compute architecture. In 2030, they will be designed to be self-monitoring and self-reporting through extensive AI for IT operations (AIOps). Except for regular hardware adds and swaps, facilities will be "lights out." This data center is designed to have zero failures, zero contention, and zero visits required. The facility monitors and maintains its operations autonomously. This represents a huge shift from past decades when a large part of a company's enterprise IT function designed, evaluated, maintained, and upgraded its data centers.

The data centers of 2030 will also be far more energy-efficient than they were 10 years prior. These facilities deliver the promise of the cloud: the right-sized allocation of resources kept at maximum utilization. Each new generation of computing and storage infrastructure adds processing and capacity storage while consuming less power and generating less heat. The lower heat footprint also reduces the energy needed to cool the facility. While quantum computing is still maturing in 2030, current generations of cloud compute infrastructure have reduced carbon emissions to meet business and government requirements.

These data centers have the processing power, network-attached capacity, and performance needed to handle the inflow and outflow of torrents of data for organizations and consumers. Examples of major data center traffic flow that will support demanding enterprise applications in 2030 are as follows:

- AI tools that assess the constant flow of telemetry data and video streams; each examines the information for particular patterns that indicate change or alarm conditions
- AI tools that direct intelligent, coordinated site operations, linking vehicles and other assets together for maximum efficiency
- Analytics tools that manipulate large amounts of data for knowledge workers
- Presentation tools that visualize the results of analytics through MR and other human interfaces
- Collaboration tools led by the metaverse, operating virtual spaces and services related to the business for its knowledge workers

The data center of 2030 plugs into the global fabric of available resources and is connected by multi-Terabit scale capacity over multiple fiber entries as the standard. The complexity of the underlying network and cloud resource management falls away. Enterprise applications are entirely abstracted from specific servers and locations. Resource management is mapped against acceptable total performance, security, compliance, and cost.

Cybersecurity: Trusted access and industry demands

While technology will improve many aspects of business operations in 2030, cyber security remains a big challenge for organizations. Bad actors will continue to try and compromise operations, steal data, threaten, extort, and cause destruction. Therefore, enterprises will remain vigilant. Ten years ago, security tools began using AI and ML to detect and alert to known attack patterns and potential compromises. Zero trust practices have minimized access to unauthorized data sources. In 2030, these practices will have graduated to full-fledged intelligent agents that work in tandem with cybersecurity researchers and specialists.

In 2030, service providers will play a role in enterprises' overall security stance; they will cut off threats before they reach an enterprise network or cloud asset. Almost 10 years ago, the concept of a secure access service edge (SASE) pulled security back into the network. Service providers now instruct their public networks to monitor and lock suspicious traffic and bad actors out of their customers' vulnerable access points. Would-be attackers cannot reach their targeted corporate assets because dangerous traffic is identified and blocked by the service provider's edge.

Enterprises in 2030 will have locked down their sites' wireless networks with strict authorization and security protocols. These private wireless networks will maintain completely closed environments. Only devices with authorized eSIMs may connect to the private network; the eSIMs in these devices owned by the organization cannot connect to any resource except the private network.

These private networks lock out any mystery devices that may try to access the worksite. Any device attempting to connect to the corporate network may be locked out or sandboxed into a limited environment. The enterprise might allow these devices permission to reach the public internet, but not to see or access any corporate resources. Traffic generated by unauthorized devices may be further limited; for example, throttling bandwidth to guarantee the corporate network is not affected, even indirectly.

Outside of the controlled enterprise environment, maintaining security is more difficult. Traveling executives, field workers, and a remote workforce all risk information access or work devices being intercepted or compromised. A work device may be taken or become infected with malware; the compromised device may be an attack vector to try and access the organization's corporate resources. However, enterprises must support the company's knowledge workers wherever they may be (at all locations and at all times), which invites vulnerability.

Widespread policies and practices, such as zero trust and data loss prevention, can reduce the damage of a breach. Yet, the damage resulting from compromised or stolen data could be more disastrous in 2030 than it would have been 10 years prior. A full breach will give criminals access to large amounts of correlated data and intelligence about the business and individuals. Enterprises, particularly those in the service industry that hold large volumes of potentially sensitive personal data, must protect this information and remain vigilant. Cloud-based security services will continue to thrive in protecting sensitive corporate assets. Security experts from different organizations will still collaborate to keep up in the arms race with bad actors, with the collective goal of protecting enterprise assets, resources, and the overall business.

B2B will be a new revenue growth engine

Service providers face sluggish revenue growth owing to government pressures on decreasing connections and service costs for household and consumer home broadband (also referred to as the 2C market), which is seeing rising penetration. However, in contrast to the 2C market, new trends are emerging in the enterprise B2B market owing to accelerated digital transformation and enterprise cloudification. This fast-growing demand from enterprise and vertical industries' lucrative B2B markets comes with expectations of guaranteed SLAs, flexible bandwidth, secure, scalable, low latency, and higher performance from service provider networks.

B2B will be a new revenue growth engine in the future. Service providers' timely unlocking of differentiated premium private line services as a B2B mainstream offering will be the gateway to success and ensure faster and guaranteed returns on capex investments.

Compared to incumbent cloud service providers, service providers are still considered as trusted partners by the enterprise sector because they understand enterprises' service requirements.

However, to remain competitive, they must adjust their business models to compete with cloud providers that already have experience and skills in synergizing cloud and network infrastructure to offer premium and faster time to market (TTM) of new services to enterprises and verticals.

Omdia Vision: The digital suite of "Private line + X" opportunity boosts service providers' B2B growth in the digital transformation era

Enterprises and verticals do not only depend on one service provider for their private line connections and connecting WAN sites; instead, they hire different service providers for better resiliency and differentiated service experiences. Therefore, Omdia recommends that service providers holistically upgrade and re-architect their traditional IP MPLS VPN private lines offering to the digital suite of the "Private line + X" portfolio that will ultimately boost their B2B revenue growth.

This differentiated digital suite of "Private line + X" represents service providers' core competency of meeting enterprise and vertical industries' heightened performance expectations in the era of complex digital transformation and cloudification. It also opens doors for new business opportunities and growth.

Omdia's recommendations for bundling the digital suite of the "Private line + X" portfolio

The holistic bundling of private lines with "**X**"(where "**X**" may refer to **premium SLAs, cloud managed LAN, SD-WAN and security service.**) will surely offer enterprises and vertical industries an opportunity to window-shop with with a higher return on investments.

The following are bundling recommendations:

1. **Premium SLAs:** Enterprises and vertical industries require faster TTM and service provisioning for new services, bandwidth on demand, and guaranteed SLAs to win in a digitally competitive world. Therefore, the help of the "Private line + Premium SLAs" digital suite ensures the holistic upgrading of traditional IP MPLS private lines to E2E SRv6 enablement and fully automated tenant-level slicing for higher service quality and backbone interconnection requirements.
2. **Managed LAN:** The digital suite of "Private line + Managed LAN" ensures one-click efficient IP network and cloud synergy, management, and integration of enterprises and verticals' LAN, Wi-Fi, and industrial IoT resiliencies.
3. **SD-WAN:** The scope of traditional IP MPLS private lines will be upgraded and extended with the holistic bundling of SD-WAN with private line. The "Private line + SD-WAN" digital suite ensures faster, flexible, and one-click cloud access connections to enterprises and verticals for existing and new branch locations, boosting new business growth.
4. **Managed security:** The digital "Private line + Managed security" suite offers secure AI-based proactive threat detection and response capabilities. And safeguards and prevents enterprise services.

Key network challenges for service providers in implementing the digital suite of the "Private line + X" B2B portfolio

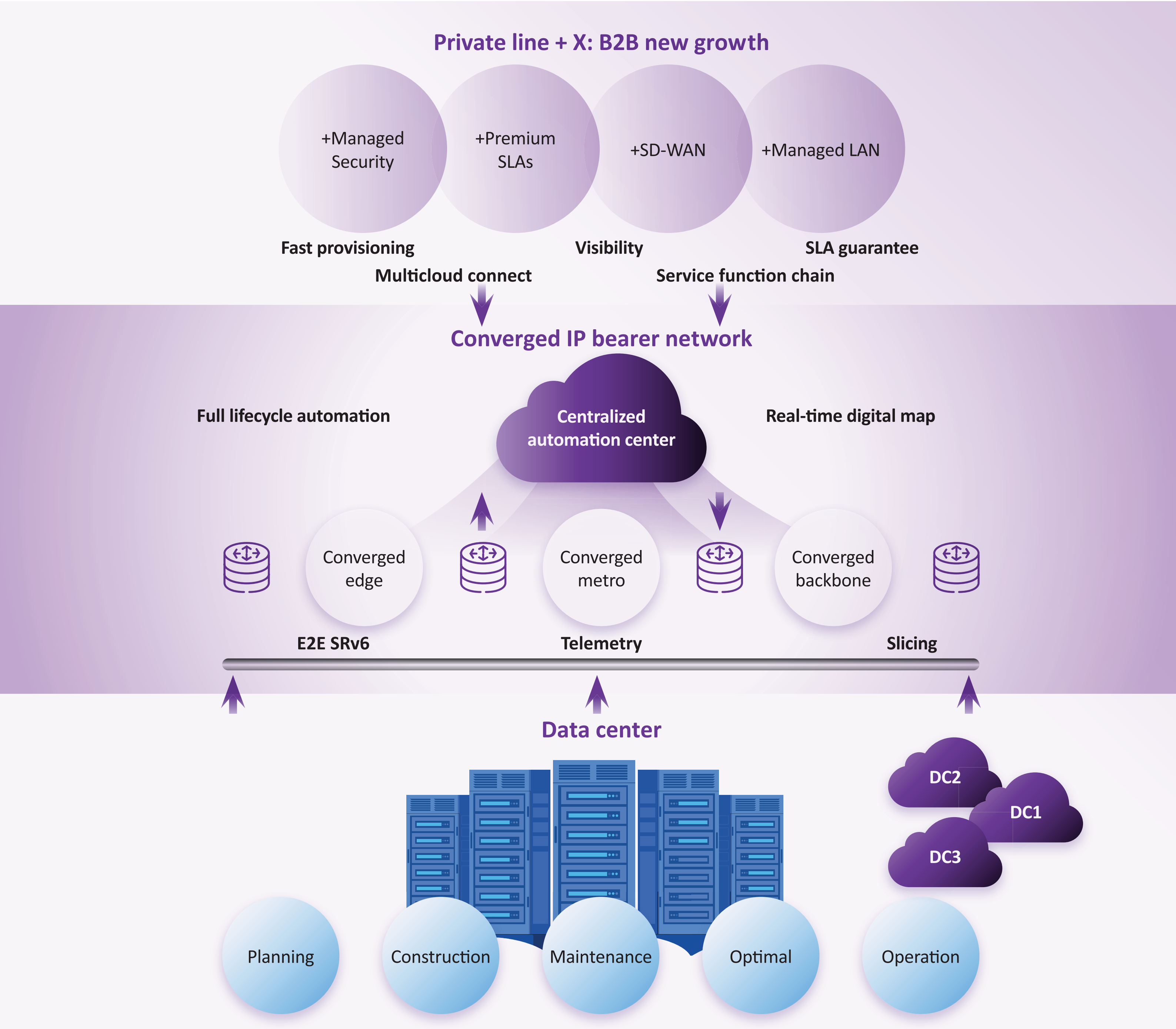
Enterprises consider service downtime a significant loss and expect service provider networks to deliver premium SLAs and high-performance experiences.

As shown in the below figure, service providers' IP transport networks now need holistic upgrading from bearer networks to data center networks to meet enterprise and verticals' key digital service trends.

1.Converged IP bearer transport network

2.Hyper-converged DCN (Data Centre Network).

Figure 6: "Private line + X" requires IP bearer convergence with E2E SRv6 and full automation



Source: Omdia

Requirements for converged IP bearer network

The E2E transport network from IP edge to backbone needs a holistic upgrade to meet the requirements of full network convergence in realizing the true essence of the digital suite of the "Private line + X" portfolio.

The following are noticeable essential network requirements:

- Converged edge for unified RAN access, 50GE site, and 100GE uplink
- Full service converged metro with 100GE downlink and 400GE uplink
- Full service converged core for 800GE interconnections
- E2E SRv6, telemetry, tenant-level slicing, and the entire network automation lifecycle

Requirements for hyper-converged data center networks (DCN)

The data center network, also known as DCN, must be upgraded to provide IT-related services for the “Private line + X” portfolio to enterprises and vertical industries in the digital era.

The following are essential DCN requirements:

- Realizing all-ethernet converged network infrastructure with full lifecycle automation
- Generalized computing power to AI-enabled computing power
- 800GE interconnection with zero packet loss and low-latency architecture
- L4 autonomous and predictive self-driving networking for multicloud interconnection

3.0 Key Net5.5G network characteristics and innovations for 2030

Evolution of 2030-oriented data communication networks

New traffic patterns for vertical industry use cases, the upcoming metaverse era, and Industrial IoT (IIoT) demand higher bandwidth, openness, network trustworthiness, and easier access to digital platforms. As a result, enterprises and the vertical industry increasingly depend on cloud computing (including ubiquitous computing power, ample storage spaces, and resilient low-latency networks) to manage their industrial automation processes. Industrial automation requires AI capabilities to solve complex and unstructured issues related to the production system. Cloud computing is an integral part of telcos' cloud strategies, blazing new rounds of discussions for CSPs to rethink and reinvent data communication network architecture and operations in the digital era.

Omdia View: Fundamental drivers for Net5.5G

Net5.5G bearer data communication (IP transport) networks will not be expected to support simple traffic flows as in the past but to keep fixed mobile converged (FMC) that enables ultra-reliable low-latency communications. Use cases include intelligent manufacturing, smart grids, cloud VR/AR, metaverse smart grids, and more. Moreover, the diversification and magnitude of network service requirements from 2025 onward will create substantial new market potential, requiring robust data communications network infrastructure.

The three fundamental catalytic driving forces in the network evolution to Net5.5G are as follows:

- AI-drives the evolution of unified networking for computing and storage resources
- Metaverse demands upgrade of network bandwidth
- Industrial digital transformations

AI drives the evolution of unified networking for computing and storage resources

- First, diversified computing, such as AI, drives the evolution of unified networking solutions for computing and storage resources and flexible cross-domain scheduling. This may be achieved by E2E IPv6 Enhanced and SRv6 networking, realizing fully intelligent cloud-network synergy.

Metaverse demands upgrades of network bandwidth

- Second, immersive applications such as the metaverse further drive network bandwidth upgrades. The demand for assurance in E2E, multi-service, slice-level service-level agreements (SLA) is also becoming an essential part of the user experience journey.

Industrial digital transformation

- Third, digital transformation has made multicloud deployment a mainstream choice for enterprises. This drives networks to provide one-hop simplified access to multicloud, heterogeneous IoT access, and E2E deterministic networking capabilities, enabling cloud-edge-device collaboration and intelligently connected industrial internet.

Omdia unleashing the Net5.5G vision

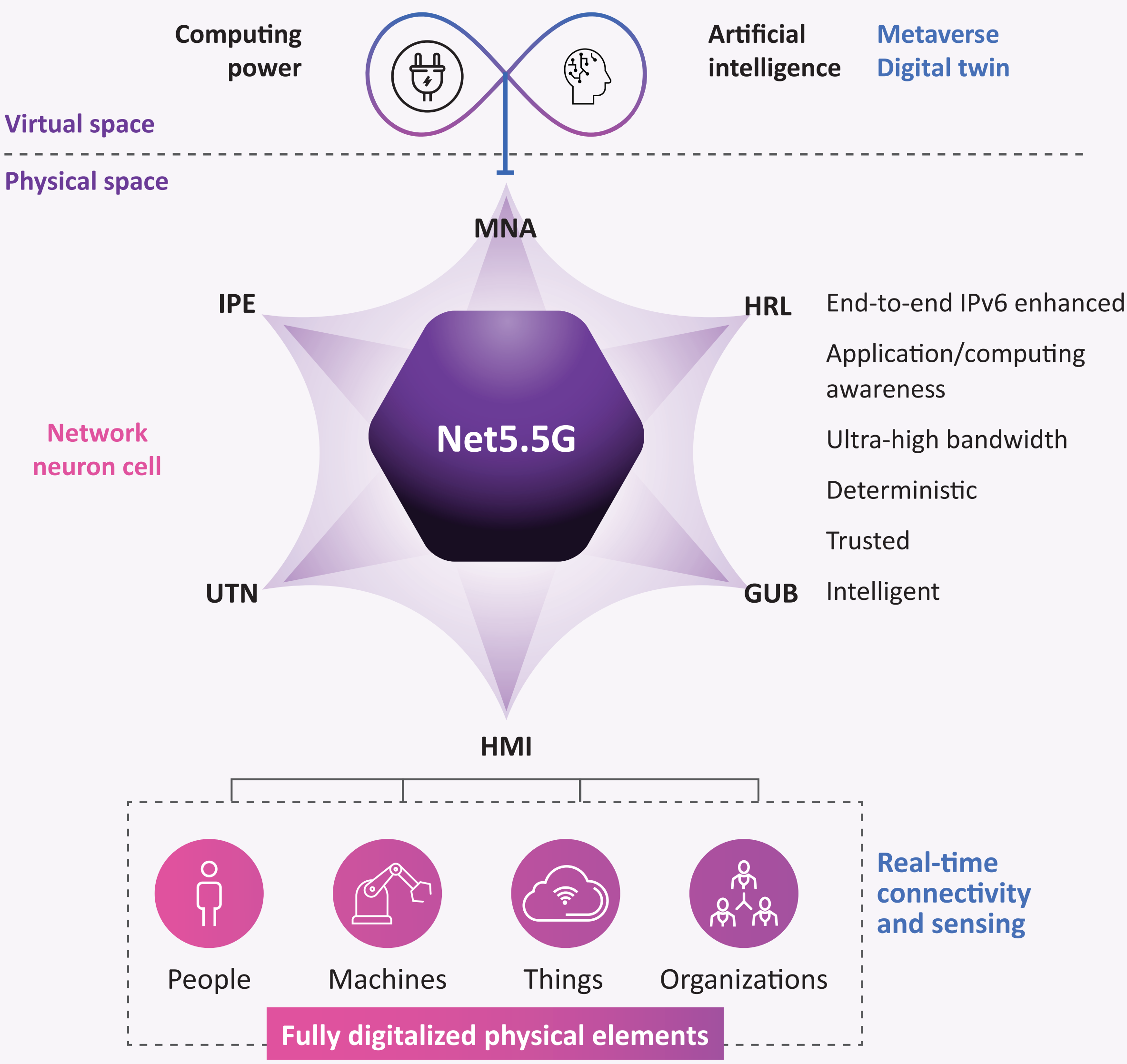
Net5.5G defines the evolution of network infrastructure in the era of ubiquitous computing, 5.5G mobile networks, and all-industry digitalization. The main capability advancement includes the convergence of computing and networks, improved 5.5G bearer networks, as well as intelligent internet and inter-sensing of everything. With the E2E IPv6 Enhanced technology as the fundamental innovation, Net5.5G realizes the deployment of WiFi 7, E2E 800GE, deterministic networking and application/computing-aware network, building an intelligent network infrastructure that connects the physical and digital spaces toward 2030.

This enables new use cases, including AI-intensive applications, immersive metaverse, and all-industry digitalization. By creating a digital neural system between the physical and digital spaces, Net5.5G opens the era of an intelligent world. It is considerably true that the development of the internet in the past decades, or the pre-5G era, has brought internet connectivity to almost every corner of the physical world. Net5.5G will play a key role in the sense of driving the migration of the network to support a fully digitalized and intelligent world with converged virtual and physical spaces in the 6G era and beyond.

Because of booming developments in ubiquitous AI computing, the metaverse, and digital twin applications, the role of internet network infrastructure is shifting from “information superhighways of the physical world” to a “neural system” that connects the physical and virtual worlds in the Net5.5G era.

Meanwhile, the key scenario of technology innovation is extending from consumer internet to industrial internet, enabling smart manufacturing and internet of everything applications.

Figure 7: Net5.5G – Information neural system for the intelligent world



Source: Omdia

Net5.5G indicators embrace the internet of everything to the intelligent internet of everything

Net5.5G innovation capabilities span from internet of everything to intelligent internet of everything, which proposes several innovations around the IPv6 standards that extend internet network infrastructure from “consumer internet” to “all-industry and all-factor industrial internet.

Evolving technology capabilities and upscaling internet data infrastructure will open the doors to an intelligent world in 2030. This will help deliver on expectations for large-scale industrial digitalization and metaverse extended realities and help enterprises use computing power from multiple clouds with agility and greater flexibility.

Net5.5G provides opportunities for those that want to implement an intelligent perception of the physical and virtual worlds by building innovative and comprehensive infrastructure for future scenarios. The chief characteristics of Net5.5G technology are capabilities supporting diverse application scenarios and requirements across different enterprise networks in 2030, as mentioned in Chapter 2.

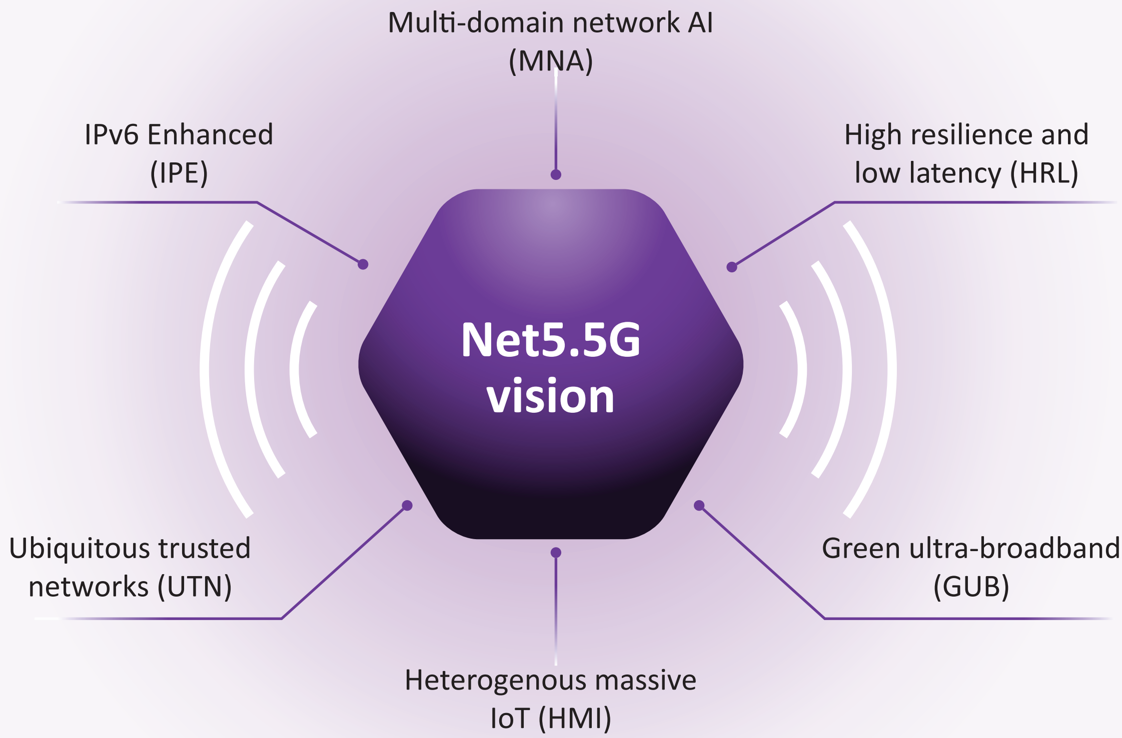
- Campus networks: Upgrading campus networks from Wi-Fi 6 to Wi-Fi 7, giving customers a peak access capability of 30Gbps; in addition, upgrading campus aggregation and backbone networks to 100GE/400GE improves the E2E ultra-broadband capacity
- WAN networks: Upgrading base station access from 10GE to 50GE, and metro aggregation and backbone transmission from 400GE to 800GE; in addition, deterministic IP networking capabilities will be upgraded from ms-level jitter to µs-level jitter
- Data center networks: The server network scale evolves from a hundred thousand nodes to millions of nodes; the maximum interface rate of data center switches is upgraded from 400GE to 800GE, and the low-latency performance is boosted from having µs-level to ns-level delays
- Ubiquitous trusted networks: Extending in-depth edge border security and implementing minute-level defense at the edge of the cloud network

The Net5.5G vision is ubiquitous, seamless, and intelligent IP connectivity (IP on everything); intelligent management allows emerging applications to use computing power from the multicloud at lower costs, with greater agility and flexibility. Furthermore, Net5.5G promotes IPv6-based upgrades for millions of terminals and devices.

To be more specific, as shown in **Figure 8**, Net5.5G evolves and focuses on two dimensions:

- Net5.5G – Fundamental network capabilities
  - Green ultra-broadband (GUB) networks
  - Multi-domain network AI (MNA) – Intelligent network
  - Ubiquitous trusted networks (UTN)
- Net5.5G – Key architectural internet innovations
  - IPv6 Enhanced (IPv6-based functionalities defined in IETF, like End-to-end SRv6 networking capabilities)
  - High resilience and low-latency (HRL) deterministic networking
  - Heterogeneous massive IoT (HMI) to unleash the potential of the industrial internet

Figure 8: The Net5.5G vision



Source: Omdia

Net5.5G – Fundamental network capabilities

Green ultra-broadband (GUB) networks

GUB makes virtual immersion a reality, referring to anything from VR and AR to MR in the metaverse era. Enterprises and vertical industries appear ambitious in unleashing this immersive experience for their remote-control industrial production systems, virtual entertainment, education, human-to-human interactions, human-to-machine interactions, and more. Therefore, the existing IP bearer networks (from access and aggregation to backbone networks) need to be upgraded with high-end intelligent IPv6 enhanced network routing platforms to support immersive metaverse interactions (between the physical and virtual worlds). Furthermore, bearer networks must meet stringent requirements for low latency, high bandwidth, and 100% network reliability and guaranteed experiences.

New services—such as the metaverse, 24K 3D VR/AR games, extensive capacity data flows (100TB per time), continuous growth in video applications, and remote holographic interactive industrial production system controls—require gigabit broadband, zero latency, and deterministic networking experiences. Green gigabit broadband speeds (currently 10Gbps; 50Gbps in 2030) with zero carbon emissions and energy savings are becoming the widespread choice for consumers and enterprises to fast-track digital transformation.

Technologies such as Wi-Fi 7 and 800G, will help achieve 10Gbps ubiquity through ubiquitous optical connection and optical transmission without sites.

The backbone network is switched from a single plane to a 3D mesh to eliminate network congestion.

Bandwidth is an essential feature of the future network and will be continuously upgraded in the next decade. In addition, industrial-grade applications, such as intelligent manufacturing, raise stringent and diversified networking requirements for reliable and quality connections, driving explosive growth in demand for high computing power and extensive storage.

Net5.5G evolution suggests continuous improvements to access, aggregation, and backbone bandwidth. The following updates are highlighted for achieving GUB networks:

- Campus wireless network upgrades from Wi-Fi 6 (10Gbps) to Wi-Fi 7 (30Gbps) peak rates
- Wired site access upgrades and supporting 10Gbps to 50Gbps to meet the following:
  - The interface rate of the data center network ranges from 400GE to 800GE
  - WAN provides flexible ultra-broadband and high throughput for cross-region computing collaborations, such as east-west traffic and computing; the network must be capable of matching enormous computing capabilities with the computing capabilities of a single data center, increased from E to 100E
  - The interface rate of the backbone transmission network ranges from 400GE to 800GE to meet future diversified traffic requirements.

Multi-domain network AI (MNA) – Intelligent network

Data center, campus, and IP-wide area networks face increasingly diversified and complex service requirements in the digital era. As a solution, AI-enabled integration in network management, control, and analysis functions helps to drive intelligent network automation. To measure network automation maturity and service experiences, intelligent network automation is classified into six levels (L0 to L5).

These six levels (L0 to L5) evaluate and measure the advantages of autonomous network services; they also help facilitate the automation and intelligent transformation of networks and services. AI and big data technologies are used to improve network planning, configuration, operations and maintenance (O&M), and optimization automation. In addition, autonomous driving networks (ADNs) also enable network automation and intelligence.

Net5.5G targets upgrading L3 (conditional autonomous) to L4 (highly autonomous) networks or in later stages, to L5 for fully intelligent ADNs.

NET5.5G helps ADNs to combine connections and intelligence to develop self-organizing, self-healing, self-fulfilling, and fully autonomous networks. These networks deliver zero-wait, zero-touch, and zero-trouble experiences to vertical industries and enterprises and enhance enterprise digitalization. ADNs use knowledge and data to drive three levels of intelligence, breaking the limits of manual processing; the three levels are as follows:

- IP network equipment intelligence
- IP network Intelligence
- Service intelligence

ADNs help to evolve network process automation from manual to intelligent and automatic decision-making to improve the overall IP network automation. Service provisioning is also reduced from minutes to seconds for L3 ADNs, which helps the system automatically orchestrate network intents based on preconfigured scenario templates. In the L4 ADN, the system can intelligently identify scenarios where the entire process can be automated, further accelerating provisioning speeds.

Ubiquitous trusted networks (UTN)

Network threats are increasingly complex and challenging to manage because of exponential developments in cloud computing and enterprise digitalization. Therefore, an intelligent and proactive AI-enabled ubiquitous network security system offers protection for cloud networks, edge, and device integrations. Net5.5G suggests the following universal trusted network capabilities:

- AI-enabled ubiquitous security protection mechanisms must quickly respond to abnormal changes and the required network and business environment levels.
- AI-based threat response and intelligent network protection can mitigate security risks in the industrial digital era
- Highly accurate and real-time ubiquitous security protects against threats at the edge of campus networks and large data center networks
- Network security loopholes should be reduced, and attack detection time should be decreased from hours to minutes or seconds
- Response and remedial counterattack time must be reduced from days to minutes to avoid long-term damage from security threats

Net5.5G – Key architectural innovations

IPv6 Enhanced E2E SRv6 networking capabilities

Solving IPv4 address depletion means adopting IPv6-based connectivity, which is imperative in the digital era. However, today's networks cannot unleash the cloud network synergy to meet the expectations for flexible scheduling of heterogeneous computing resources with existing IPv4 addressing techniques. As a result, millions of enterprises are migrating to the cloud and demanding converged and intelligent IPv6-based transport bearer networks for connecting cloud resources.

Net5.5G, leveraging on IPv6-based IETF protocols innovations, aims to fine-tune IPv6 functionalities defined in IETF and helps build an enhanced, large-scale IPv6 network. IPv6 Enhanced with SRv6 (segment routing) protocol ensures simplified and unified E2E IP addressing and tunneling signaling capabilities, reaching data centers, end systems, campus networks, and reducing cross-domain conversions. Therefore, Net5.5G ensures increased reachability, simplified networking, and network programmability, marking a landmark evolution in IP network history. In a cost-effective way, SRv6 takes traffic engineering beyond the multiprotocol label switching (MPLS) era, enabling robust SLAs and programmability with the following capabilities:

- E2E SRv6 networking providing application/computing awareness
- Upgrading tenant-level network slicing granularity from the K-level of 100K-level

IPv6 is the foundation, while IPv6 Enhanced (with AI capabilities) allows for new service innovations and unleashes intelligent network connectivity. In addition, an IPv6-only network ensures fast computing power at the edge, complete SRv6 support for one-stop access to multiple cloud environments, and FlexE-based complex slicing for deterministic user experiences. IPv6 Enhanced networks allows for new service innovations, differentiated QoS through network slicing, and shortened provisioning times to match cloud application requirements through automation and software-defined networking (SDN) controls. IPv6 Enhanced will drive the necessary networking innovations and new E2E functional support for SRv6, AI, and Bit Index Explicit Replication IPv6 (BIERv6), and network controls for SDN automation in edge computing, IIoT, network convergence, and enterprise networking.

Net5.5G SRv6 innovation efficiently deals with tons of traffic loads in the metaverse era and provides flexible and elastic ultra-broadband capabilities, improving user experiences and network utilization efficiency and implementing intelligent on-demand access. In addition, data centers with E2E unified protocol and SRv6 achieve zero packet loss, high throughput, and efficiently release computing power.

This innovation will help service providers integrate cloud network synergy, and help enterprises access agile multicloud computation. Intelligent IPv6-enabled networks are required to carry an increasing number of critical services in enterprise verticals and digital transformation. The demand for intelligent connections, industrial automation, and immersive service experiences renders IPv6 Enhanced network and AI-enabled automation necessary as enterprises increasingly shift to the cloud.

IPv6 ensures intelligent path planning, O&M visualization and automation, traffic engineering, SLA assurance, and application perception. In addition, full SRv6 and BIERv6 encapsulation for packet multicasting (BIERv6) shortens provisioning times to match cloud application requirements.

This intelligent cloud network synergy requires the proactive inclusion of simplified IPv6-only reachability and unified forwarding across all IP network domains with no extra signaling requirements. Therefore, this cloud-delivered synergy will transform IP edge, traditional device-centric metro networks, and core networks into modern IP networks.

High resilience and low-latency (HRL) deterministic networking

In the future, the IP network will extend from the office network to the production networks that demand deterministic networking with low latency and high reliability for industrial control systems and lossless application bearer networks. High network flexibility and low latency are critical to end users' application experiences in XR of the metaverse era.

Net5.5G ensures a deterministic IP networking experience with improvements in low latency for IIoT for mission-critical applications of 5.5G data center interconnect networks (DCNs). It also helps to ensure:

- Reduced static delay in DCNs from 1µs to 200ns
- Highly scalable and technology-driven advanced Dragonfly topology, enabling DCN at a scale of million servers
- Network jitter improvement from ms to µs, with reliability reaching industrial demand of 99.9999%

Deterministic Industrial networks

The existing IP networks are reserved for best-effort services, which cannot meet the industrial internet's diversified, robust service requirements for ultra-high latency and jitter SLA assurance for production services. Net5.5G promotes the internet's network infrastructure from best efforts to deterministic IP networking experiences, enabling core production services to be migrated to the cloud and helping customers achieve robotic automated industrial production with improved efficiency.

Lossless and low-latency DCN

The global computing capability will be increased by 100x, and the DCN scale will be upgraded from a hundred thousand servers to millions of servers. In this case, DCN performance improvements (with a static delay reduction from 1µs to 200ns) will be imperative. In addition, the new storage medium (storage class memory [SCM]) will be used, with I/O latency increased from 200µs to 20µs. Network jitter will be brought down from ms to µs, while reliability increases from 5x to 6x nines to meet the following requirements.

The network slicing capabilities of Net5.5G and its deterministic IP technologies inherit the connectivity of IP networks for achieving E2E millisecond-level latency and µs-level jitter with low loss and service delay variations. In addition, the metaverse and industrial internet require real-time data collection.

Net5.5G leveraging IPv6 promotes IP-based upgrades of last mile devices, provides IP addresses for various terminals, resolves the problem of non-interworking for industrial network protocols, and further improves the direct connection capability between intelligent terminals and the cloud.

Heterogeneous massive IoT (HMI) to unleash the potential of the industrial internet

Heterogeneous IoT is an emerging field that transforms future living in smart homes, smart cities, the industrial internet, smart agriculture, smart hospitals, and intelligent transportation. With the network's scale expanding, its connection capability will be enhanced continuously, and the number of devices on it will increase, requiring fast processing at the network edge.

IPv6 Enhanced innovation accelerates the adoption of the IPv6 protocol stack for use across wider heterogeneous IIoT applications, connecting terminals, contents, and networks. IPv6 Enhanced enhances IPv6 and realizes the following benefits:

10x IoT terminal connections	End system IPv6 penetration rate rising to 90%	Industry equipment connection rate rising to 80%	IP-based industry equipment penetration rate rising to 70%

Deploying Wi-Fi 7 with one converged IP bearer network (using network slicing to divide the physical network into many logical networks) ensures service quality of experience. It prevents slice congestion while ensuring high bandwidth and reliability for heterogeneous IIoT scenarios. Furthermore, one-click operations, predictive analysis, and fault diagnosis enhance operational efficiencies.

What does the new Net5.5G framework tell us?

The AI-enabled digital wave is driving an unprecedented network change, with heightened enterprise, vertical industry, and consumer expectations for the next decade. As we approach 2030 and looking at the future of the datacom industry, the E2E underlay IP network will evolve to a higher bandwidth, based on emerging use cases and applications. The E2E underlay IP network will also require higher reliability and AI-enabled improved network intelligence for emerging enterprise and trending consumer applications such as 5G, IoT, 8K, cloud VR services, and private leased line 2B services.

- Video traffic's immersive experience is expected to continuously boost bandwidth, with video applications requiring 10 times the current bandwidth.
  - The **8K video traffic** is increasing at a rate of 33%. single stream can take 100Mbps BW, and some high-fidelity holograms can reach up to 10Gbps. In short, the video experience is reaching new heights with the maturity of 8K and Glasses-free 3D immersive experience at home.

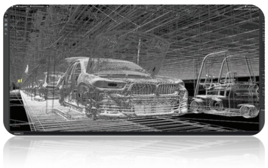
8K HD video

100Mbps
Per stream

Glasses-free 3D

Multi Gbps
Per stream

- **XR and industrial metaverse applications** also require high bandwidth, with a demand of 10Gbps access for an XR-enabled campus, including single classroom education and factories.



XR-enabled Factory

10Gbps
Per 1000m²

XR-enabled Education

10Gbps
Per Class

- **Multi-cloud strategy is now a clear strategy** for enterprises' digital transformation. All enterprises' (small, medium, or large) IT applications accelerated the migration of IT applications to multi-cloud or hybrid cloud for better management, data safety, robust system reliability, and professional SaaS provided by specific cloud providers.

  On the flip side, this cloud-edge, public-private combination of inter-cloud connectivity makes the network more complex. Network automation rises to reduce complexity and improve agility.

- **Industrial digitalization** is accelerating in all verticals. IT/OT access and enterprise branch networks are upgrading to 10Gbps with the following observations in campus IT, OT, and enterprise leased line scenarios.

  - **Campus IT networks** – In campus IT networks, all high-density offices require 10Gbps at the office desk, with 50 end-devices connections per access point (AP) and 40 live video conference sessions. **Education campus IT networks** are transforming from traditional to intelligent education that demands 10Gbps per class. There are eight desks per class and the six VR devices per desk demand 10Gbps per class.

Gbps → 10 Gbps

  - **Campus OT networks** – Industrial automation requires that machinery be wirelessly controlled with seamless **10Gbps** coverage to the unit and 13 cameras per production line. Each production site camera requires at least 100Mbps per camera with a 60% concurrency rate and 8.6Gbps total bandwidth with no delay and zero packet loss. In intelligent manufacturing, 10Gbps to the production line is a new trend that runs 1,000 instruments per distributed control system (DCS) with 10Mbps bandwidth per instrument required.

100 Mbps → 10 Gbps

  - **Enterprise leased lines** in enterprises' IT applications are migrating to the cloud, requiring 10Gbps to branch. High-definition video conference sessions are the hot trend and need at least 160Mbps per meeting room stream. Similarly, all enterprises need strict video surveillance, with each video camera requiring at least 10Mbps.

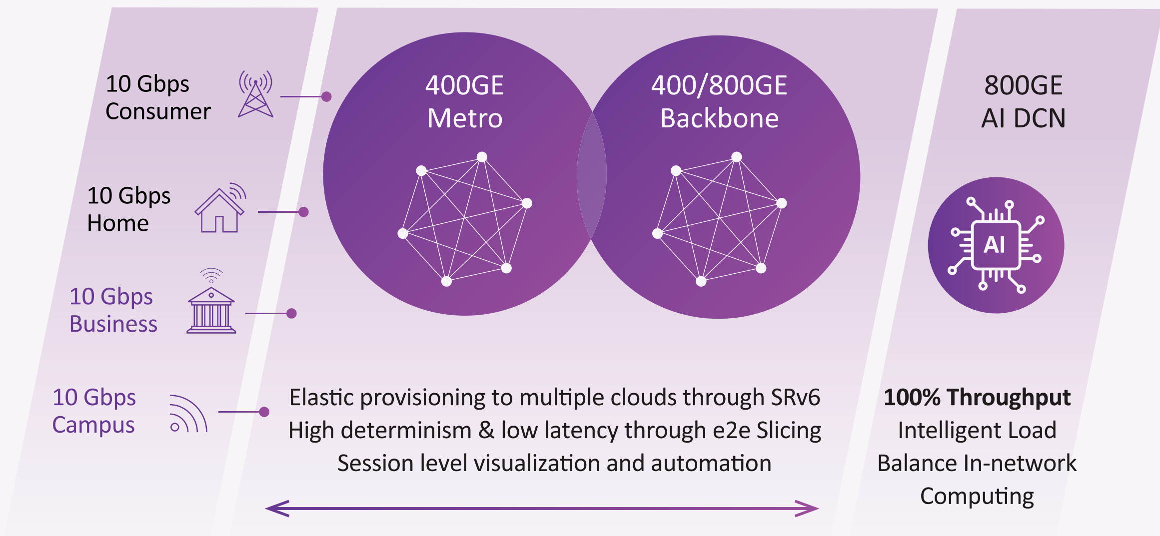
Gbps → 10 Gbps

AI DCN plays a crucial role in increasing AI computing efficiency

- 5G, cloud, and AI are powering all industries. AI computing applications require strict networking and high-end efficient computing power requirements as it ensures extreme scalability for intelligent computing for single- and multi-level tenants of consumers and industry verticals. DCN networks should not be overlooked, with AI catalyzing the DCN construction from traditional DCN mode to AI-DCN networks. A simple packet loss rate of 0.1% can now tremendously reduce the computing power of AI training by 50%.
- AI-DCN ensures service and cloud providers have fully autonomous driving DCN networks with guaranteed capabilities of rapidly locating faults, root cause analysis, predicting traffic patterns, evaluating daunting network risk failures, and optimal network path selection, etc.
- AI-DCN plays a crucial role in increasing AI computing efficiency to enable AI capabilities to grow by 500 times come 2030 and onward, ensuring that service providers achieve ultra broadband, high throughput, and low latency for their underlay IP networks.

The above quick overview of emerging use cases and applications demands that the next generation of 400GE/800GE IP aggregation network, which enables quadruple 10Gbps access and AI DCN, is necessary, as shown in the figure below.

Figure 9: Quardruple 10Gbps Access + 400GE/800GE IP Transport + 800GE AI DCN



Source: Omdia

By 2030, diversified at-home consumers, enterprises, and vertical industries (e.g., healthcare, education, transportation, manufacturing, logistics, and mining) will aggressively demand a strong end-to-end underlay IP transport bearer network foundation and automated network openness with on-demand multi-cloud interconnections.

The next level of IP networking is possible with a true splash of AI-enabled NET5.5G that helps to modernize and revitalize by ensuring the actual value of the future evolution of the datacom industry

The following are some key points to note:

10Gbps to the consumer, home, business, and campus network is necessary for ultra-broadband and deterministic E2E experience.

Enabling **400GE** metro and **400G/800GE** backbone.

Enabling **800GE** AI DCN network for **500x** AI computing power in 2030.

On the flip side, the wave of AI computing efficiency in the form of ChatGPT and other AI tools dramatically accelerates AI chip shipment expectations. NET5.5G-enabled AI-DCN plays a crucial role in the E2E datacom network, with 400GE metro and 800GE backbone capability.

Meanwhile, flexibility and deterministic networking will be guaranteed by evolution at the data plane by using new technologies such as E2E SRv6. SRv6 innovation efficiently deals with heavy traffic loads in the metaverse era. It provides flexible and elastic ultra-broadband capabilities, improving user experiences and network utilization efficiency, and implementing intelligent on-demand access. In addition, data centers with E2E unified protocol and SRv6 achieve zero packet loss, high throughput, and efficiently released computing power.

To increase efficiency and agility, reduce automation complexities, and increase the intelligence of network provisioning, multi-layer visualization and automation should be adopted throughout the network infrastructure in a full life-cycle pattern. A unified digital map of all the connection flows enables the proactive preservation of the service level that the specific service or customer needs by adequately measuring the status of the IP layer and SRv6 connections.

In short, many service providers and vendors are now having an agreed industry consensus that Net5.5G will ultimately fill the gaps of 5G, 5G-advanced, and future 6G network. Net5.5G will enable key eMBB, URLLC, and mMTC features because the NET5.5G framework catalyzes bearer network access, aggregation, and core network bandwidth roadmaps to unleash complete digitalization.

4.0 Summary and outlook

The digital economy is driving unprecedented network changes with heightened enterprise, vertical industry, and consumer expectations for the next decade. Industrial digitalization empowers businesses and demands digital transformation with agile, efficient, and flexible ICT network solutions for in-depth human and machine interactions. As a result, billions of people and objects will be connected and interacting in 2030; personalized gigabit bandwidth experiences for industry and consumers will be the key differentiator. In addition, low-latency deterministic service experiences with 1ms latency and 99.999% availability will be critical to intelligent industrial digital transformation and the metaverse era.

The evolution of the data communication bearer network in 2030 demands agility, low latency, high bandwidth, high reliability, and security with massive computing power and large storage space for human-to-human and human-to-machine interactions. E2E tunneling through IPv6 with SRv6 implementation will support the commercialization of the industrial internet and help to solve the IPv4 address limitations for millions of IoT devices. Timely adoption of IPv6 innovation will accelerate and facilitate Industry 4.0 use cases, such as smart transport and smart manufacturing. The combination of IPv6 and network slicing helps build a capillary network, ensuring efficiency and agility in the industrial internet era. Converged IP bearer networks with E2E SRv6 transport for access, metro, and backbone networks will improve adaptability, capacity, network simplicity, and time to market, while allowing for more intelligent networks. This meets the requirements for business verticals and delivers network as a cloud.

The whole industry must collaborate to tap into the industrial digital economy and make the metaverse a reality. A thriving ecosystem is required to achieve Net5.5G, defined simply as “IP on everything.”

The vision and standards for Net5.5G will be finalized within the frameworks defined in IETF, IEEE, etc.

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