DRIVING THE FUTURE: UNDERSTANDING THE LANDSCAPE OF CLOUD NETWORK CONVERGENCE

WORLD BROADBAND ASSOCIATION

This report analyzes the need for cloud network convergence that drives the digital economy and will facilitate the connectivity of an intelligent world. The report acts as a guide to understanding the landscape of cloud network convergence. It also expands on the enduring value of IP and optical networking for cloud network convergence and suggests the key architectural requirements.

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SUMMARY

CLOUD-NETWORK CONVERGENCE ENABLES TRUE BUSINESS SUCCESS IN THE DIGITAL WORLD

Information and communications technologies (ICT) are speeding up digital transformation on all fronts. Gigabit fiber networks, 5G, artificial intelligence (AI), and cloudification offer the promise of an intelligent and modern digital era that needs agile, efficient, and excellent network experiences for digital enterprises and consumers.

Timely adoption of digital and intelligent initiatives based on robust and deepening cloud-network convergence, including extensive big data integration, AI-enabled network intelligence, security automation, and supercomputing powers at the edge and data center will strengthen the digital transformation infrastructure.

With this accelerated development and deepening of cloudification and digital transformation, the traditional role of communications service providers (CSPs) is transforming into that of intelligent digital network service providers (DSPs). Therefore, it is time for service providers to seize the business potential of strategic opportunities offered by new technological innovations in intelligent cloud-network integration.

Cloud-network convergence drives the digital economy and will facilitate the connectivity of an intelligent world, just as the power grid accelerated the second industrial revolution. It helps service providers ensure and construct the transport bearer network architecture with five constructs:

- Elasticity on demand
- Guaranteed levels of service
- Cross-domain orchestration
- All-scenario production
- Tenant-level operations

This industrywide research-led network technology consultative white paper presents the standpoint of World Broadband Association (WBBA) expert working group 4 on the technology of cloud-network convergence, outlines the industry backdrop, and discusses network challenges hindering digital transformation. It investigates 2025 and beyond, the possibilities for consumers, and business use cases.

The white paper also expands on the enduring value of IP and optical networking for cloud-network convergence and suggests the key architectural requirements.

It concludes by suggesting that “cloud and network as one” helps DSPs to speed up the construction of the congestion-free new transport infrastructure with better network scalability, enhanced intelligence, and deterministic experience.

INDUSTRY BACKDROP AND TRENDS ANALYSIS OF CLOUD NETWORK INFRASTRUCTURE

Success in the digital economy depends on network connectivity, where digitalization is the critical priority for all DSPs in an ongoing digital revolution.

Millions of enterprises have moved to the cloud or made concrete plans to do so soon. Network and service ubiquity is the ultimate dream of all DSPs, because this ubiquity promises to ensure deterministic and exceptional user experiences for their enterprise and residential customers.

The realization of an intelligent cloud-network convergence and full integration in the form of carbon-free intelligent cloud-oriented IP and optical transport networks is now an imperative and inevitable choice for service providers: necessity is the mother of invention.

A VISION OF CLOUD-NETWORK CONVERGENCE

Cloud networks are now an inevitable trend of digital transformation, a new digital infrastructure that firmly glues communication, technology, and supercomputing power infrastructures. As a result, many service providers are set to adopt a cloud-network convergence vision as their key strategic direction in accelerating digital transformation to meet the demands of enterprise and individual broadband consumers for real-time network connectivity, service agility, and multicloud collaborations.

Cloud-network convergence is a way forward or guiding principle that helps to modernize service providers' existing bearer (IP and optical) network infrastructure and to leverage one-click access to multicloud (private, public, or hybrid) interconnections. It can also enable the use of centralized AI-enabled cloud network automation for the underlay network infrastructure and fully utilize the potential of telemetry and deep-dive big data analytics. With the deep convergence of communication technologies and service-oriented information technologies resources, intelligent cloud-network converged infrastructure breaks the boundaries between cloud and network, seamlessly connecting the network and enabling multiple clouds and edge points.

In true digitalization, service providers' cloud-network convergence helps their enterprise and vertical industries customers by providing a single and cohesive network platform to connect their various work locations for smooth working to increase business efficiencies and revenue.

The significant value of cloud-network convergent digital information architecture is that it ensures an excellent user experience with end-to-end network intelligence, higher network availability, openness, flexibility, adaptability, and end-to-end network security.

The notable benefits of cloud-network convergence are as follows:

- Intelligent, reliable, ubiquitous, and always-on network connectivity
- Service agility, scalability, and flexibility to help optimize business processes and revenue
- Faster time to market for new services with multicloud interoperations and interactions for quick data sharing and analysis
- Complete network visibility and deterministic service experience
- All-around, one-stop integrated network and service security protections
- Enhanced data protection, privacy, and data sovereignty and more trusted services
- AI-enabled ultra-automated intelligent network automation
- Increased service and business competitiveness for service providers in comparison with cloud providers

MARKET CATALYSTS AND TRENDING DYNAMICS

Despite severe economic headwinds, digital transformation is accelerating; cloud-network convergence is an inevitable trend and an inevitable demand for many enterprises and individual customers. The primary enablers and driving forces of this accelerated digital acceleration are the enterprises' and vertical industries' interest and continuous investments in their cloud and network upgrades initiatives and home broadband users' interest in cloud-based new entertainment and lifestyle applications.

The year 2022 was tough with macroeconomic crises and low confidence levels. The global economic slumps with increasing cost-of-living pressures and economic uncertainty may lead some consumers and enterprises to reevaluate their communications spend. Still, it is unlikely that the service provider telco market will drop or that enterprises and consumers will cancel their network subscriptions altogether. It is true that telecom markets show resiliency and are likely to escape severe impact because of the extent to which telecom services are regarded as essential utilities.

Now, the industry expectations of the service providers' role are changing: from being simply last-mile connectivity providers, they are now expected to be intelligent and integrated DSPs for both business-to-business (B2B) and business-to-consumer (B2C) services. Customers now look for an operator that offers the best bundling of digital services, manages their network and IT resources remotely, and offers the most reliable and intelligent network connectivity.

The following are market-driving trends and dynamics for boosting cloud-network convergence. Details of each use case are discussed in detail in ***2025 and beyond: The possibilities of consumer and business use cases***:

- The enterprise digital transformation race, cloudification vision, and 5G overall catalyze and cement the need for an intelligent cloud network.
- The fourth industrial revolution (Industry 4.0), Industrial Internet of Things (IIoT), and consumer IoT accelerate global digital transformation.
- The B2B2X verticals industry is a new market and revenue opportunity.
- "Informatization" drives the demand from specialized vertical industries (especially hospitals, education, finance, etc.) for the availability and growth of an industry private cloud network.
- Smart city development initiatives drive the replacement of multiple e-government extranets with one-city, cloud-enabled secure urban networks.
- Cloud-native applications reduce the time needed to adopt digital services or solutions and demand one-hop interconnection.
- One-stop e-commerce is demanded by SMEs' digitalization and cloudification strategies.
- The major traffic contributor has become 4K and 8K ultra-high definition (UHD) video.
- Cloud virtual reality (VR) is required for typical emerging B2B and B2C use cases.

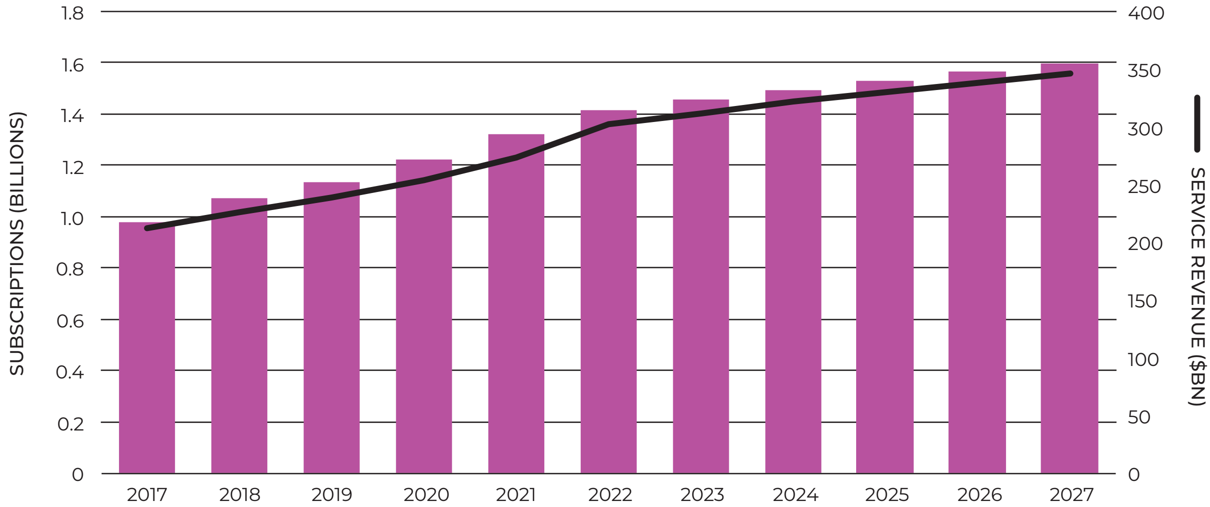
B2C FIXED BROADBAND MARKETS

The challenge for operators is to maintain their ARPU levels in the face of increasing competition. As competition grows across the broadband world and many markets approach saturation, maintaining ARPU is becoming increasingly important to service providers that wish to succeed. Traditional metrics such as subscription numbers and service revenue begin to flatten. Therefore, telco operators need new key performance indicators (KPIs) and to tap emerging service offerings to gauge the success of their service offerings. In underdeveloped consumer home broadband markets, ARPU can be driven by subscription growth. But as markets mature, service providers need to move their ARPU strategy toward bundling emerging new video services with content and excellent customer service.

Increased reliance on home connectivity for work, study, and socializing during the COVID-19 pandemic has led to a step change in preferences, placing customer experience, connection reliability, and content bundling at the top of consumer priorities. Additionally, huge increases in bandwidth-hungry services such as media streaming, UHD video, and cloud VR have accelerated the demand for reliable, high-speed, low-latency broadband.

As shown in **Figure 1**, Omdia's report *Broadband ARPU Growth Strategies – 2022* forecasts global fixed broadband subscriptions to grow from 1.1 billion at the end of 2018 to 1.6 billion in 2027 to meet consumers' home broadband expectations. Service revenue is expected to grow in tandem and to reach $346bn by 2027.

FIGURE 1: GLOBAL FIXED BROADBAND SUBSCRIPTIONS AND SERVICE REVENUE, 2018–27



SOURCE: OMDIA

B2B MARKETS

The B2B market is a new growth engine. It ensures an incremental revenue opportunity for the service providers if they successfully differentiate from the cloud and internet content providers. Service providers reinvent the B2B market in two directions, one for large enterprises and the second for vertical industries' digitalization journeys. First, enterprises and vertical industries are busy with network upgrades to enable digital transformation. They evaluate their investment portfolios against those of peers and rival enterprises to measure their digital transformation pace. Therefore, service providers must adapt and customize their offering to the changing needs and demands of enterprises and verticals, focusing on cost reduction, flexibility, and sustainability.

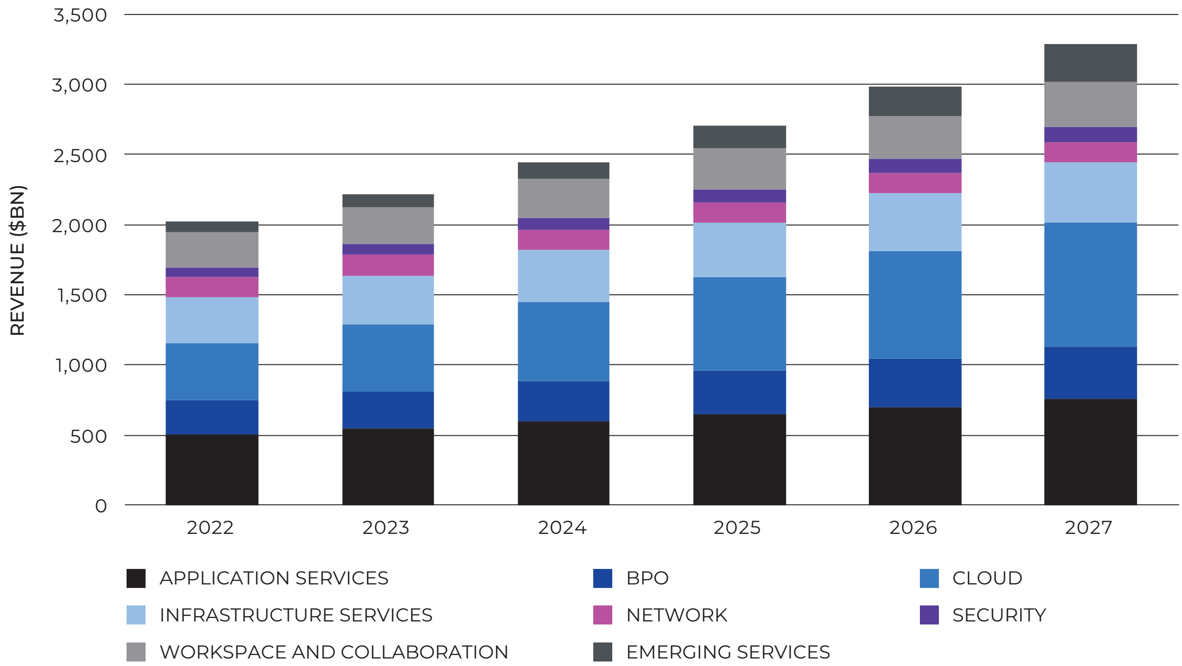
Omdia's enterprise forecasts research for 2022–27 found double-digit growth despite macroeconomic disturbances. As a result, the global enterprise services market will increase from $2.0tn in 2022 to $3.3tn by 2027 with a 10.2% CAGR from 2023–27 for all enterprise services, driven by emerging technologies, multicloud, security, and business process outsourcing (BPO).

As shown in **Figure 2**, traditional network services are slightly declining as workloads increasingly move to the cloud and are supported by emerging technologies such as AI and blockchain. However, network connectivity remains an essential and crucial baseline for enabling other services, including the cloud. Therefore, it will still provide sizable opportunities, often in combination with cloud, security, infrastructure, IoT, and so on that may be included in the same deal. As a result, service providers tend to win multitechnology contracts based on their underlay optical, IP, and gigabit home broadband optical-network credentials while building their digital and consulting capabilities.

Service providers prioritized essential telecommunication services to win the digital race. Their consistent impulse is to keep networks up and to run with the latest routing innovations for enterprise digitalization and to fulfill consumer broadband demands. Omdia's service provider routing and switching team observed a solid first quarter in 2023 in comparison with the first quarter of 2022. The routing and switching market reached $16.4bn in the rolling four quarters to 1Q23.

Omdia's latest market share analysis of service providers' IP routing and switching found a record first quarter of 2023, a new market share for service providers in routing and switching.

FIGURE 2: GLOBAL ENTERPRISE SERVICES FORECAST BY CATEGORY, 2022–27



SOURCE: OMDIA

In short, to tap the massive potential of evolving B2B and B2C markets and maintain their digital supremacy, service providers must capitalize on their network infrastructure and cloud-network convergence experience to help fulfill the dreams of home broadband consumers and enterprises for digital transformation.

INDUSTRY BACKDROP: NETWORK CHALLENGES HINDER DIGITAL TRANSFORMATION

Service providers' strong determination to support enterprise digital transformation by building an intelligent cloud network infrastructure with a strong emphasis on cloud-network integration synergy and ultimate convergence in their underlying transport network is accompanied by increased requirements and challenges in the modernization of the underlay transport bearer network.

It is also a bitter reality of the past that service providers, being the network infrastructure owners, have already lost a big chunk of business benefits to internet cloud providers, web scalers, and over-the-top (OTT) cloud service provider rivals because of their slow acceptance of the pace of their cloud deployment initiatives, long times to market, and lengthy and cumbersome network and service provisioning procedures.

On the other hand, OTT cloud providers have had an aggressive strategy of moving closer to the edge or nearer to users for better low-latency user experiences through network functions virtualization and easy multiple cloud access. As a result, cloud providers' determination to build their network infrastructure backbones is becoming a significant threat to service providers in many regions.

From an industrial perspective, the real value of cloud-network convergence must be in ensuring a solid foundation on which to develop the digital economy. But this industrywide cloudification of B2B industrial and B2C home broadband use cases creates key network expectations and requirements. More secure and closer collaboration is needed between enterprises, networks, the cloud, and applications in the era of intelligent cloud networks.

Service providers' successful sailing in industrial digitalization depends on how they leverage cutting-edge digital and intelligent cloud network technology solutions in their networks. They must find answers for the network challenges that hinder their digital transformation journey and the digital transformation of society as a whole:

- **Enterprises demand multicloud connections with single-point access.** How can providers provide multiple-service enhanced capabilities to network edge sites that can enable multicloud interconnections that adapt to hybrid multicloud interconnection requirements?
- **How can differentiated service experiences be assured** by shifting from best efforts to deterministic and high-quality service experiences?
- **How can service providers realize quick network provisioning and rollouts** to achieve the network-on-demand principle or network as a service (NaaS) for better service agility in the digital era?
- **How can service providers move from single-point security to an end-to-end network security architecture** for networks, devices, cloud, and applications for the best service assurance and service experience?
- **How can network resources be optimized** by visualizing network resources and intelligently meeting dynamic traffic change uncertainties?

Therefore, it is important that industry stakeholders, including service providers and system vendors, work together closely and comprehensively to consider and plan a robust IP and optical bearer cloud network transport network.

The transport bearer network not only connects wireless and core networks but should be foundational and built on principles of intelligent NaaS cloud-network integrated frameworks that provide enormous computing power to drive B2C and B2B industrial use cases for a robust digital era and answer the questions above.

TECHNOLOGY BACKDROP: DEVELOPMENT OF CLOUD-NETWORK CONVERGENCE

As owners of the networks, service providers are fully aware of the urgent demand of millions of enterprises for a unified cloud-based, service-oriented network for their production systems. A deep-dive transport bearer network modernization strategy is imperative for DSPs to get the lion's share from this digital connectivity race in which B2B2X is their new revenue-generating sector.

Service providers are exploring ways and brainstorming different network and cloud synergy options with a strong belief that IP and optical-based network transformation, with intelligent cloud-network convergence based on AI-enabled network automation, will play a more significant role in the successful implementation and acceleration of enterprise digital transformation, enabling growth in all services. It is hard for a traditional cloud network to meet the high-performance and ultra-low-latency requirements of digital services. Real-time cloud availability and terminal edge cost performance must be continuously improved through multicloud collaboration, cloud-edge collaboration, and even cloud-network-edge collaboration.

The technological development of cloud-network convergence transformed the traditional three-layer (access, aggregation, and core) network infrastructure into two layers that revolve around the basic resource layer of the network and constantly advance and deepen from the cloud, including intracloud, intercloud, and cloud access to multicloud collaboration and cloud-network-edge-terminal collaboration.

- **Intracloud network integration.** Cloud-network convergence initially occurred in the intracloud network (in the data center). To meet the demand for high-frequency, fast transmission of massive data brought by cloud services, intracloud integration enables automatic deployment, operations, and maintenance of the virtual cloud network of a data center (DC) through consistent security and network policies for container and virtualized service applications. Spine-leaf/Clos architecture and extensive Layer 2 network technology were introduced to realize the organic combination and integrated operation of network capability in DC and cloud capability.

- **Inter-DC traffic.** The focus of cloud-network convergence shifts to intercloud networks, that is, data center interconnection (DCI). With the dramatic increase of inter-DC traffic, the fast forwarding and efficient carrying of east-west traffic between DCs is realized by deploying large-capacity, nonblocking, and low-latency DCI networks.
- **Cloud access (cloud to cloud or edge integrations).** Because of the surge in working demands from enterprises, accessing cloud and software-as-a-service (SaaS) traffic and cloud access have become a new focus of cloud-network convergence. Different types of services require differentiated cloud-access private-line solutions. Some new types of networking technology for building wide area networks (WANs) and easily interconnecting with branches, such as software-defined wide area networking (SD-WAN), offer a software-defined way to enable simple, flexible, and low-cost cloud access from the enterprise's headquarters to subbranches. This hybrid cloud-network integration empowers one-click access from smart devices to cloud services to build the enterprise IoT with an intelligent and smart edge. At the same time, some other industries have quality requirements, such as committed VIP bandwidth, stable low latency, and higher reliability. In this case, users will use optical transport network (OTN) technology to access the cloud.

Based on our observations, we make three important technology strategy recommendations for accelerating intelligent multicloud network integrations in the digital era.

OBSERVATION 1: SERVICE PROVIDERS HAVE A STRONG TRANSPORT BEARER NETWORK FOUNDATION BUT NO CLOUD CAPABILITIES

Service providers lack cloud capabilities despite having a strong bearer network. As a result, theyare losing revenue to OTT players.

SUGGESTION
Service providers with cloud construction capabilities that have not yet been exploited should consider evolving to a converged 5G/F5G and 2B transport bearer network. This logical architectural convergence of physical equipment will bring embedded resource management and service scheduling based on physical layer streamlining. Cloud-network convergence brings "one network, one cloud-integrated capability" for cloud-data convergence, cloud-intelligence convergence, and cloud-edge convergence.

OBSERVATION 2: SERVICE PROVIDERS HAVE A STRONG TRANSPORT BEARER NETWORK FOUNDATION BUT WEAK CLOUD CAPABILITIES

Service providers have a solid underlying transport bearer network. However, they have insufficient and weak cloud-network synergy capabilities because of a lack of cloud capabilities and openness (e.g., network resource visualization) in the network.

SUGGESTION
DC-centric network construction and high-quality private-line connection to the cloud will help the achievement of intelligent cloud-network synergy. Service providers will attract higher revenue by selling their high-quality private lines with guaranteed SLAs for cloud connection. Enterprises in the digital era need reliable and dedicated private-line connections to the cloud. Providing automatic service provisioning and loading with one-stop cloud network subscription services is vital to success.

OBSERVATION 3: SERVICE PROVIDERS HAVE A STRONG TRANSPORT BEARER NETWORK AND CLOUD CAPABILITIES

Some service providers have strong transport bearer and cloud capabilities. However, they need enhanced strategies to attract higher revenue and stay competitive.

SUGGESTION
Integrating cloud-network integration with building multicloud (including private, public, and hybrid) and bundling with a strong network foundation is imperative for successful results. Service providers should leverage their existing private-line network connections and empower

their enterprise and vertical industry customers with e-commerce-like service experiences that enable one-stop service subscription and automated service provisioning. In addition, service providers can build and leverage their hybrid cloud capabilities to provide combined connection and cloud services and attract higher revenue. By implementing an intelligent cloud-network integration strategy, service providers can offer the following key benefits to their B2C and B2B vertical industry customers:

- **Easy integration:** fast and flexible integration with in-house hybrid cloud and third-party clouds
- **Elasticity:** bandwidth scalability and flexible adaptation to various service traffic thresholds
- **High security:** end-to-end efficient device-network-cloud-application integrated security architecture to provide secure interconnection between private and public clouds
- **Self-service portals:** empowered enterprises through the user-friendly web-based deployment of cloud networks for service creation and bandwidth scaling

2025 AND BEYOND: POSSIBILITIES FOR CONSUMER AND BUSINESS USE CASES

Demand is moving toward 5G, gigabit fiber networks, cloud, and IoT applications needing strong network performance. In addition, the deepening of enterprise and vertical industries' digital transformation and multicloud adoption means that bearer networks must carry an increasing number of vital services.

All enterprise and individual scenarios put new requirements on cloud-network convergence. Enterprise customers need to enhance their competitive advantage with the help of multicloud deployment, high-performance cloud-edge collaboration, and integrated service provisioning. For government customers, digitally intelligent cities and digital communities have increasingly high requirements for cloud capabilities and integrated security. Cloud-based applications such as extended reality (XR) have become a new entertainment and lifestyle experience for individual customers. Finally, for households, cloud-based innovative family services are increasingly indispensable.

Cloud-network convergence must adapt to many constantly evolving use cases and application scenarios. Cloudification of the network requires improving cloud capabilities, and the construction of digital platform capabilities also requires the cloud network's capabilities to be constantly upgraded.

For a detailed study of use cases and applications, refer to *WBBA Broadband Case Study Success Stories*.

THE DRIVE FOR BANDWIDTH IN 2025 AND BEYOND

In 2025, broadband networks will be expanded: from connecting individuals and homes they will connect everything from everyday objects to anything we wear and interact with. This evolution of in-home broadband connectivity opens new business horizons and demands high-bandwidth, ultra-low-latency, and high-performance networks. By 2030, 13.7 million new consumer devices will be connected daily, with more than 9 billion mobile connections and 33 billion consumer IoT devices.

The WBBA predicts that by 2030 broadband access networks in advanced countries must achieve reliability greater than 99.999%, latency of less than 1ms, and extremely low jitter.

Key "at home" digital trends and use-case scenarios demand gigabit bandwidth, low latency, and guaranteed quality. The data from Ookla's Speedtest Global Index™, which shows improvements in broadband performance, also shows that demand for next-generation FTTx technologies is multiplying. Ookla recently presented at the Communications Association of Hong Kong's Symposium 2022, "Challenge and Opportunities for Fiber Gigabit Economy." Markets such as Hong Kong and Macao are advanced in fixed network development and adoption, characterized by low levels of connection growth and intense fiber penetration. Ookla's Speedtest Global Index ranks Hong Kong 5th and Macao 12th on median fixed download speeds as of November 2022.

- At-home bandwidth increases with low latency:
  - Web 3.0: high bandwidth, intelligent, and open
  - Smart home
  - Entertainment: 4K–8K UHD, high bandwidth, and optimizing content distribution networks (CDNs) for video services
  - Cloud gaming: ultra-low latency
  - XR (augmented reality / virtual reality [AR/VR]) applications: both high bandwidth and low latency
  - Working from home: increases downstream and upstream
  - Learning from home: more clients per household demands more bandwidth

WEB 3.0

Web 3.0 will be a paradigm shift in the evolution in connectivity, changing how people socialize and consume entertainment services. Its development will mean a new internet phase that has the potential to be disruptive and usher in a new era. The internet will become more intelligent, open, and AI enabled.

SMART HOME

Edge cloud applications are integrated with broadband access service to enable the smart home. To meet the requirements of smart homes, leading service providers such as China Telecom deploy cloud resources at the edge of the metro area network. They are connected directly to an optical access network. Using these edge cloud resources, service providers aim to provide personalized cloud services for each family, including home video service (IPTV) through soft terminals, video-monitoring storage, intelligent image recognition services, and so on.

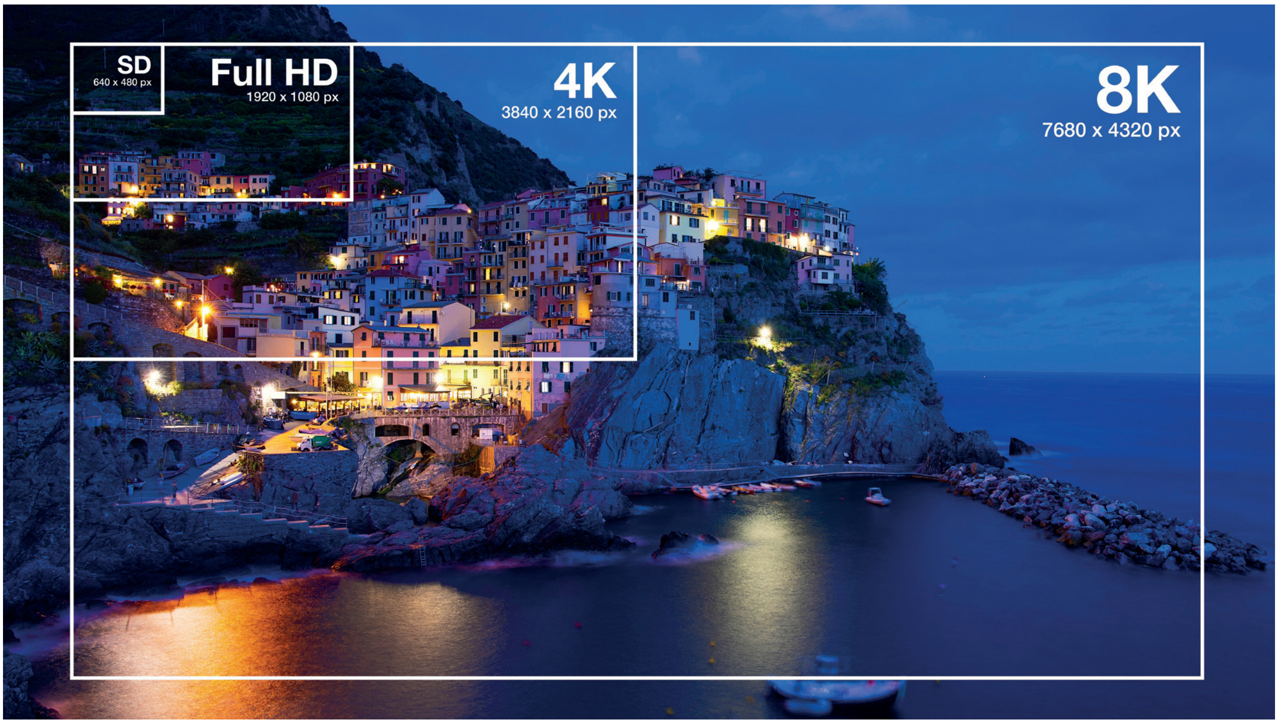
FIGURE 3: THE SMART HOME WILL MAKE EVER-INCREASING DEMANDS ON HOME BROADBAND

SOURCE: FREEPIK

4K–8K UHD VIDEO

A UHD video experience with high bit rates and evolution from SD to 4K and finally 8K for home users is an inevitable trend for video development. Home broadband consumers and enterprise users need a clearer, smoother, richer experience. Concurrent requests for 4K and future 8K-enabled videos for lifestyle applications, entertainment, videoconferencing, learning or working from home, and so on will lead to a considerable upsurge in demand and flooding in the bearer network. Many leading service providers, such as China Telecom, have deployed distributed CDN on the edge cloud to support high-quality video services and introduced eDNS technology to realize traffic control. China Telecom has provided distribution CDN service for 4K HD video services with edge cloud nodes, dramatically improving the quality of video services. The low convergence of UHD drives with zero delays and no packet loss drives the innovation of intelligent cloud-converged transport bearer networks because traditional bearer networks are designed only for internet architecture with a high convergence ratio. Today, video traffic accounts for around 80% of all traffic and is the leading driver for consumer home broadband.

FIGURE 4: EVER HIGHER-RESOLUTION VIDEO FUELS A RAPID RISE IN INTERNET TRAFFIC



SOURCE: FREEPIK

- As we move toward 2025, the demand for high-quality 8K UHD video applications grows exponentially. Consumer adoption of advanced VR applications will increase bandwidth requirements from 100Mbps per channel to 5Gbps per stream. Low latency, low jitter, adaptive bit rates, buffering, and dynamic optimization are all requirements for an excellent user video experience.

XR APPLICATIONS

The gap between the physical and digital worlds will narrow with XR immersive experiences. Healthcare, online shopping, and cloud gaming are all set to change the ways people interact with healthcare professionals, do shopping, or play on-demand cloud games. Cloud VR includes family-oriented entertainment, live gaming, education, and shopping capabilities in the form of scenarios including VR IMAX, VR panoramic videos, and live broadcasts for an interactive and immersive experience. Numerous intelligent connected devices—including mirrors, weighing scales, cameras, headsets, and wearables—are used for real-time experiences. However, network bandwidth is still a potential showstopper for the immersive experience because a tiny glitch can severely damage individual service experiences.

FIGURE 5: XR WILL NARROW THE GAP BETWEEN PHYSICAL AND DIGITAL WORLDS

SOURCE: FREEPIK

MANAGED MESH WI-FI

A service provider managed mesh Wi-Fi solution can optimize Wi-Fi performance for all customers. The key component of this Wi-Fi optimization is a cloud platform from which both provider and consumer devices can be managed and optimized. Combining this with embedded algorithms in the Wi-Fi access points (APs), service providers can bring the best performance to their customers, ensuring the best overall broadband experience. The outcomes are reduced opex, reduced customer churn, and increased revenue generation through the sale of more higher-tier broadband and other value-added services. In addition, the industry proposes a new Wi-Fi networking solution: fiber to the room (FTTR). FTTR enables Wi-Fi coverage through optical fibers, providing a more consistent service experience with consistent coverage, better device handover times, less application freezing, and more consistent broadband speed. There is a growing trend among operators to offer broadband plans tiered by speed and features related to in-home network quality. With its promise of even more excellent quality, FTTR could allow the creation of yet more premium broadband tier plans that fit alongside operators' existing tariff portfolios.

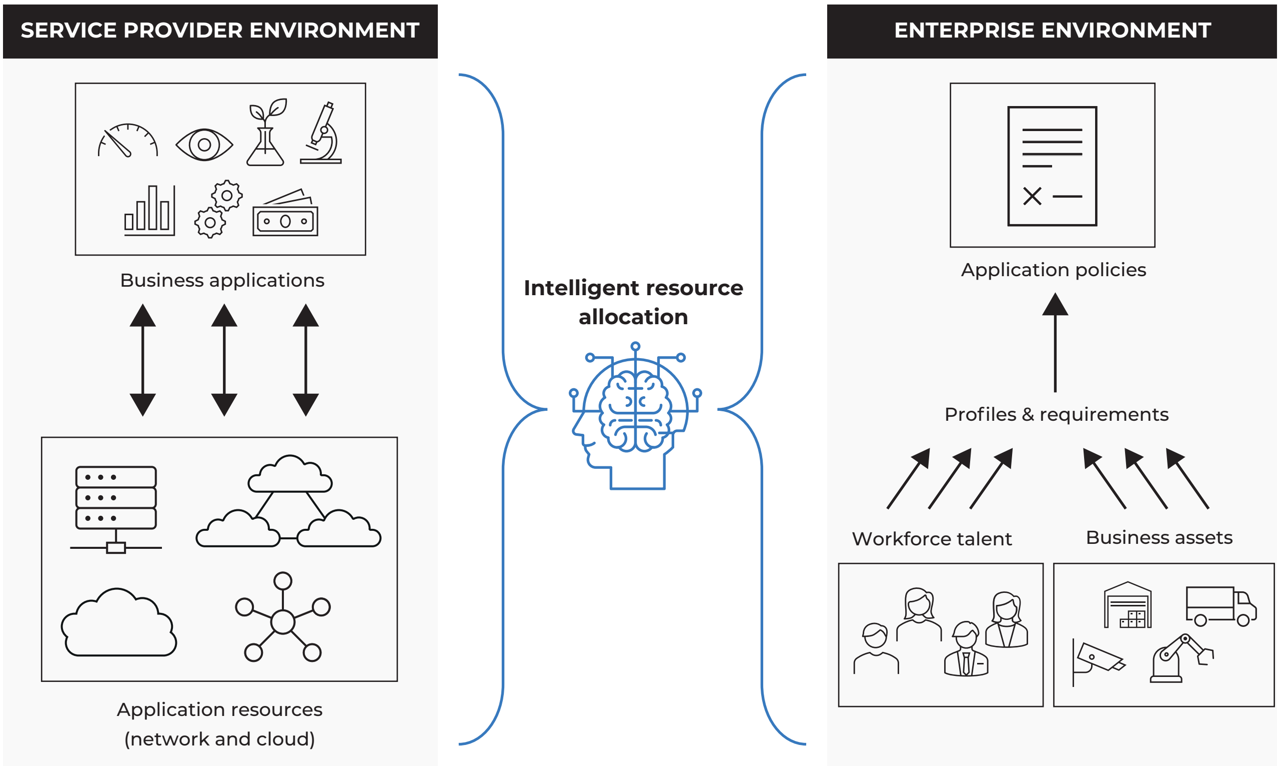
APPLICATION-DRIVEN ENTERPRISE AND VERTICAL INDUSTRY USE CASES BEYOND 2025

Enterprises, including SMEs, accelerate their efforts to optimize access to cloud-based digital applications and services as part of their cloudification journey. In a fully connected digital metaverse economy, the future enterprises, SMEs, and verticals industries all aim to deliver any digital product, anytime and in the way the customer wants, before the customer knows they need it.

For businesses in 2030, cloud services have been mainstream for over two decades. Enterprise workloads have shifted almost exclusively to the cloud—a collection of intelligent, interconnected clouds—that adapt to changing application loads, user and device needs, available computing 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 6 shows the model of how people, devices, applications, and supporting resources coordinate intelligently to support business outcomes.

FIGURE 6: INTELLIGENT COORDINATION OF RESOURCES FOR THE ENTERPRISE



SOURCE: OMDIA

Enterprise digital transformation, cloudification, 6G, and 10 gigabit fiber networks catalyze and cement the need for an intelligent cloud network. Telco service providers already have a strong network infrastructure advantage because they build and manage networks, unlike OTT internet content providers (ICPs), cloud providers, and web scalers. Unleashing an intelligent NaaS with cloud-network integration will fuel their enterprise customers' digital transformation journey and help them achieve their goal of providing one-stop digitalization services.

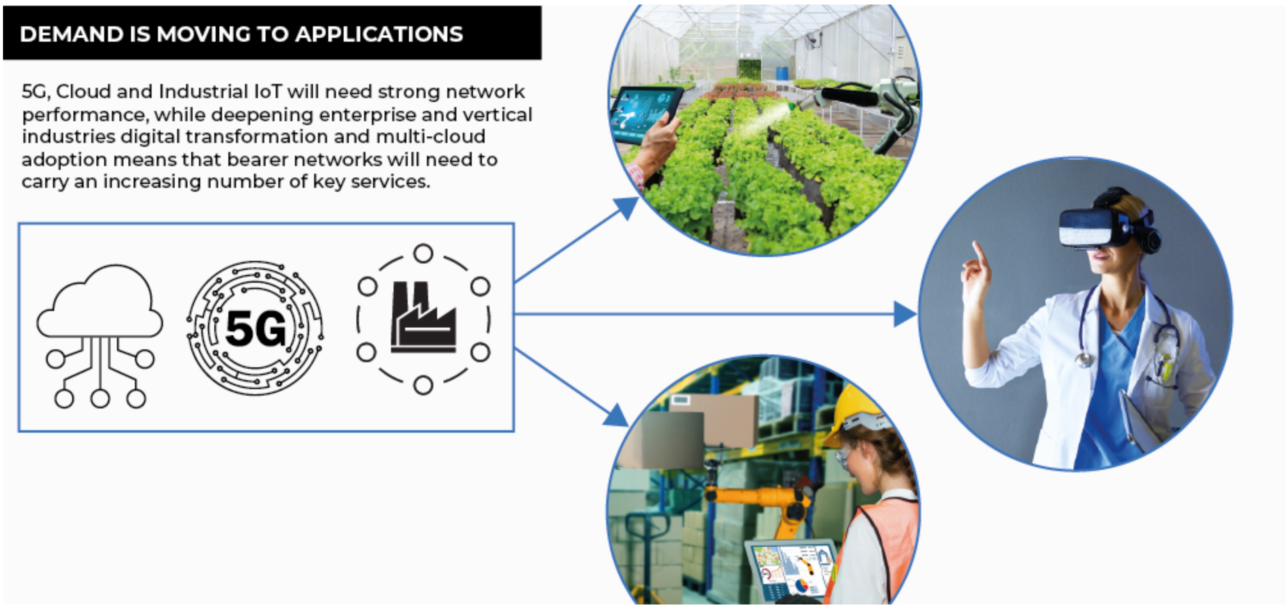
As 5G/F5G goes deeper, cloud service transformation is happening everywhere, with enterprises moving their critical ultra-low-latency business applications to the cloud. ICT is redefining the campus network by merging LAN with WAN, and cloud-enabled WANs are the new control point for centralized operations and management. The B2B2X vertical is a new market and revenue opportunity. B2B is relatively new but will emerge as a more significant revenue market segment of the digitalization journey. The urgent readiness of converged intelligent cloud networks demands robust transport infrastructures with secure, intelligent cloud-network integrations in metro and backbone transport. Service agility will be imperative for all industrial and enterprise digital transformation journeys.

Let us briefly look at different enterprises and vertical industry digital transformation possibilities. Below are examples of how new technology drives intelligence and efficiency for essential enterprise functions from 2025 onward. For example, new capabilities will improve commercial transportation and operations in cities, hospitals, and finance; 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.

THE FOURTH INDUSTRIAL REVOLUTION ACCELERATES THE GLOBAL DIGITAL TRANSFORMATION

The fourth industrial revolution is accelerated because of the advancements and evolution of AI-enabled technological breakthroughs. Industry 4.0 embraces technologies including the Industrial Internet of Things (IIoT), AI, big data, cloud, digital twinning, and security. IIoT is the leading technology that permits smooth collaboration and convergence between information and operational technologies (IT and OT) for the autonomous and unmanned operation of thousands of devices and machines. Moreover, as shown in **Figure 7**, in the digital economy, many verticals are moving from physical to digital and creating new high-bandwidth traffic demands.

FIGURE 7: CLOUD-NETWORK CONVERGENCE IS THE BASIS FOR THE SUCCESS OF ENTERPRISE AND VERTICAL INDUSTRY TRANSFORMATION



SOURCE: FREEPIK

SMART CITIES DEVELOPMENT

The “smart city” drives the replacement of multiple e-government extranets with a “one-city urbanized network,” where logical separation of data with complete security-walled isolations between different organizations and adjustable one-stop cloud network services are the key for efficient and digital working. Intelligent and smart city construction is a critical part of government ICT charter directions toward modern urbanization. These smart city initiatives require DSPs for the integration and security isolation of multiple siloed connected networks and adjustable one-stop cloud network service to the e-government cloud.

CAMPUS NETWORKS

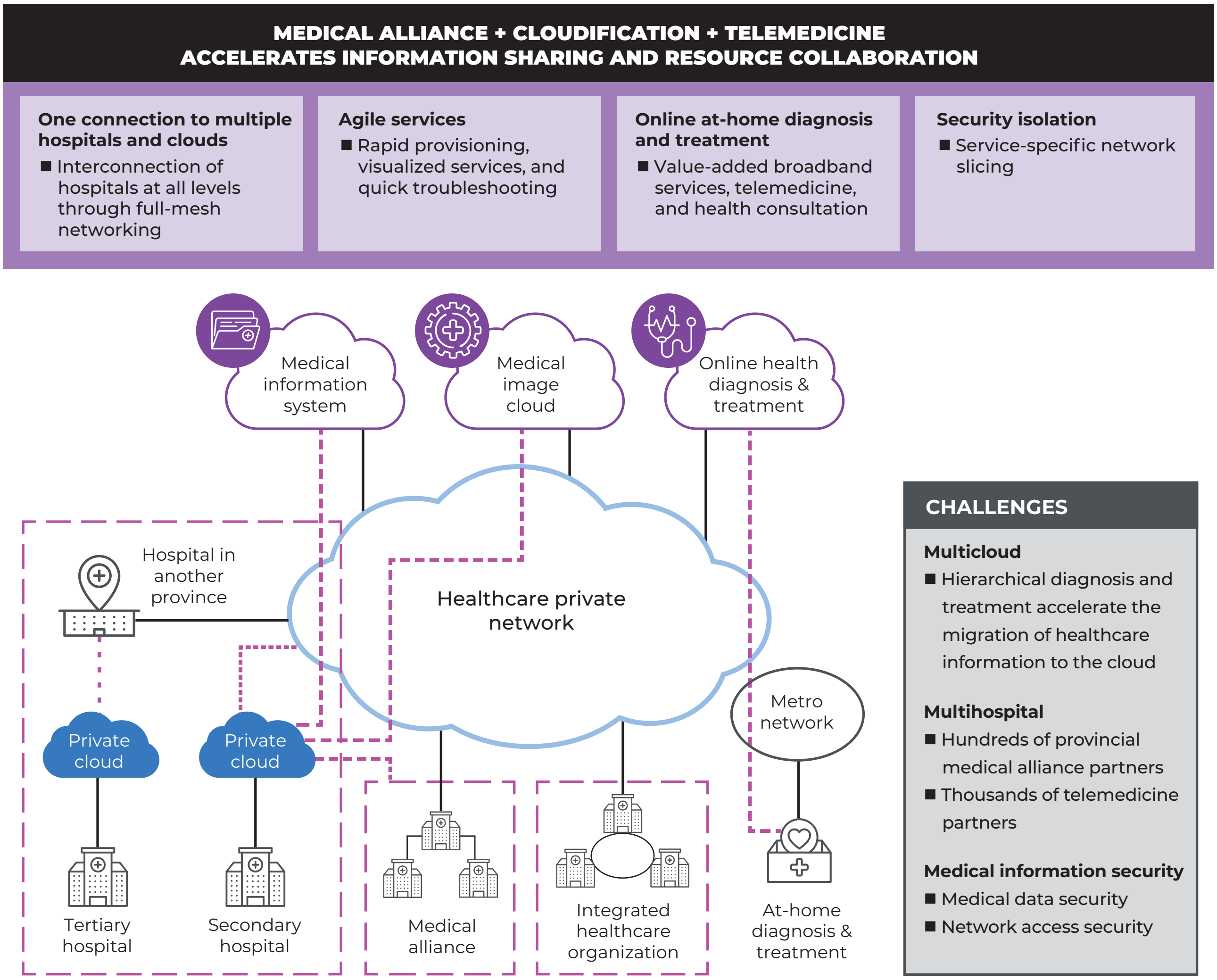
Informatization drives the growth of industry private cloud networks. Enterprise and vertical industry digital informatization demands a high-quality private network with increasing requirements for secure multicloud interconnections for efficient working. Many industry verticals, especially healthcare, education, finance, and manufacturing, already attach great importance to informatization for information sharing and multicloud collaborations. Therefore, a sliced-based and supercomputing, secure, high-performance and high-quality bearer network infrastructure will be imperative to maximize the critical value for the verticals’ digitalization journey.

SMART HOSPITALS

Around the world, the healthcare industry requires end-to-end secure, intelligent cloud integration to provide a service fit to meet natural disasters such as the coronavirus pandemic. As **Figure 8** shows, healthcare now demands a robust and reliable network from service providers for a proper digitalization process. Some of the significant current challenges for the healthcare industry are as follows:

- **Inability to control network quality to meet required latency and bandwidth requirements.** The most significant and backbone enterprise sector of any country, healthcare faces problems in acquiring the desired network quality with zero packet loss of critical information shared across multicloud private and hybrid networks.
- **The difficulty of ensuring network reliability.** Because of high traffic levels on service providers' nonsliced networks, it is difficult to ensure network resiliency during outages and disasters.
- **Complex operations and management (O&M).** Slow network provisioning and complex management of the interconnections between remote sites and the leading hospital center cloud network is the biggest challenge during national emergencies.

FIGURE 8: INTELLIGENT CLOUD-NETWORK INTEGRATION FOR MULTICLOUD ACCESS



SOURCE: OMDIA

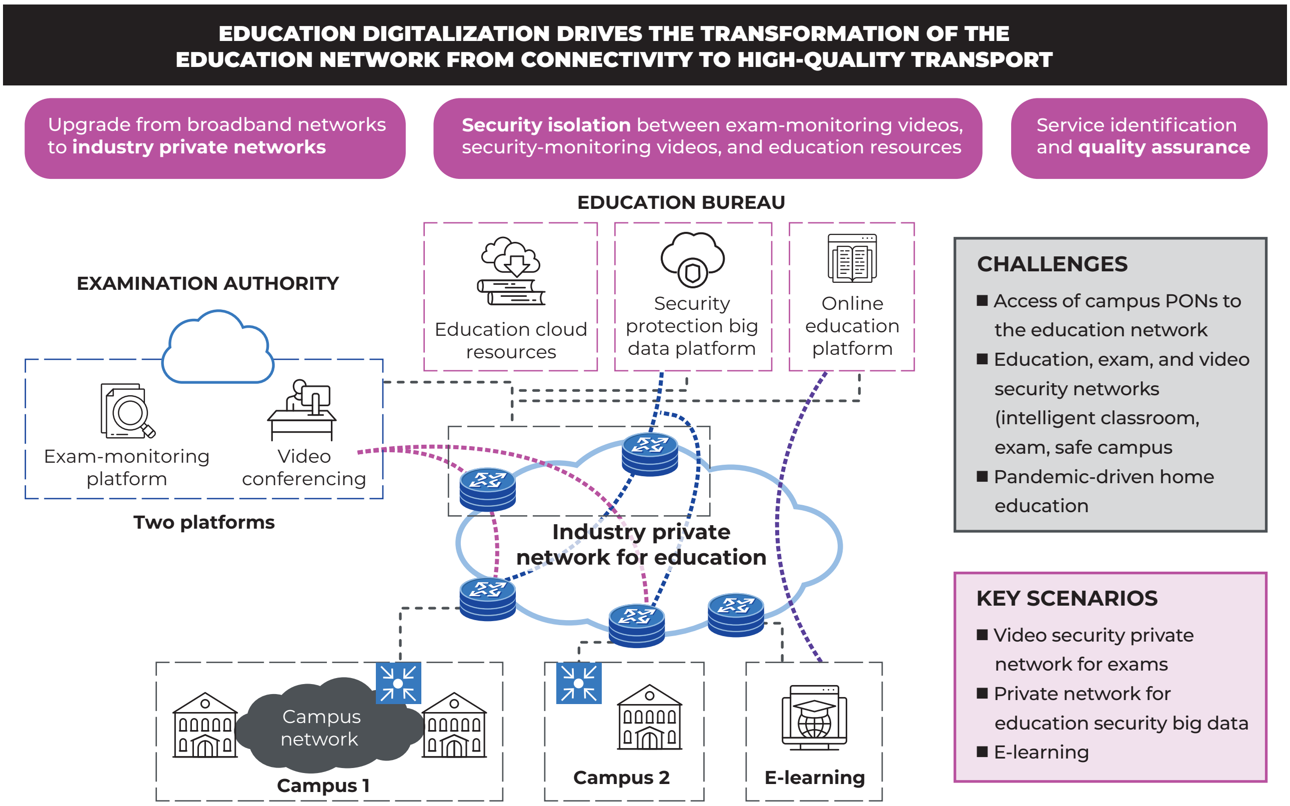
Intelligent cloud-network integration with end-to-end secure IP hard-pipe sliced private networks, and one-connection multicloud access ensures a deterministic service experience for the healthcare industry. This AI-enabled IP network automation with SRv6-enabled hard-pipe sliced network can meet the dedicated-bandwidth requirements of critical medical services with low latency and reliable connections.

SMART EDUCATION

The second-largest vertical that needs immediate attention is education. The pandemic precipitated a rapid increase in learning from home. As a result, a study model previously only commonly used by distance-learning programs was practiced by students from kindergarten to the postgraduate level.
Tasks such as accessing education provider networks from the home broadband connection, using video to ensure security for examination systems, and conducting group research in real time with sharing of critical data require a high-quality CSP transport network with an excellent user experience with fewer distortions and data packet losses.

Education digitalization is the next opportunity for service providers because it demands secure and reliable private campus networks for educational institutions. In addition, secure exam monitoring, rich research resources with a single agile connection for multicloud access, and high service quality assurance demand intelligent cloud-network integrations.

FIGURE 9: INTELLIGENT CLOUD NETWORK DRIVES DIGITAL TRANSFORMATION OF A CONNECTIVITY-FOCUSED NETWORK FOR ONLINE EDUCATION



SOURCE: OMDIA

SMART TRANSPORTATION

By 2030, the network-connected public transportation infrastructure and vehicles will have become even more intelligent. Smart highways and autonomous vehicles will reduce travel times, accidents, 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) 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 security and help the business avoid liability by showing that 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 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.

SMALL AND MEDIUM ENTERPRISE DIGITALIZATION

One-stop e-commerce is vital for SME cloudification strategy. Millions of small and medium-sized enterprises are set to go on the cloud and advance their digital transformation journey for intelligent and digital working business efficiency. Their overall cloudification strategy aims to achieve simplified one-hop access to multiple clouds without worrying about network and IT resource handling. In their digitalization journey, SMEs expect DSPs to provide a combo package integrating cloud access bundles with stable internet network connectivity and intelligent e-commerce-like services.

UHD VIDEO

UHD video has become the major contributor to traffic on bearer networks. A UHD video experience with high bit rates and evolution from SD to 4K and finally 8K for home users is an inevitable trend of video development. Home broadband consumers and enterprise users need clearer, smoother, richer experiences. Concurrent requests for 4K-enabled videos for lifestyle applications, entertainment, videoconferencing, and learning and working from home lead to a gigantic upsurge and flooding in the bearer network. The low convergence of UHD with zero delays and no packet loss drives the innovation of intelligent cloud-converged transport bearer networks, because traditional bearer networks are designed only for internet architecture with a high convergence ratio.

CLOUD VR, THE ULTIMATE BOOSTER FOR CLOUD-NETWORK CONVERGENCE

VR is an emerging generational leap in the ICT industry. The global VR market ecosystem is developing with improvements in content, headsets, terminals, and applications. Cloud VR is gradually emerging to replace inconvenient and expensive mainstream localized VR. Cloud VR introduces the concepts and technologies of cloud computing and cloud-based rendering into VR service applications with latency that must be deterministic for VR immersive interactions. Rendering of the display and sound output, including encoding and compression, is done in the cloud, and the output is then sent to users through high-speed and stable bearer networks. Content is created, codified, and managed in the cloud and finally distributed to users with continuous improvement of content, quality, and immersive experience.

FIGURE 10: THE “HEAVY LIFTING” FOR IMMERSIVE VR IS MOVING TO THE CLOUD

SOURCE: FREEPIK

B2B enterprises and vertical industries need a more precise understanding of industry requirements and the customization necessary. It can be quickly popularized in scenarios with large and clear commercial and consumer bases. In the next few years, many B2B VR applications are underway, such as remote enterprise training, industrial workshops, government services, military and firefighting training, medical surgical training, and the industrial metaverse.

TRENDS IN AI AND HIGH-PERFORMANCE COMPUTING AND THE IMPACT ON SERVICE PROVIDERS

Data is multiplying, and cloudification is an essential enabler in the emerging and high-growth market of AI, cluster computing, IoT, and high-performance computing (HPC) applications. Emerging computing services, such as AI-enabled cognition; automatic, autonomous AI; brain-like intelligence; generative AI; and HPC, will be widely used in people's work and personal life, providing efficient, accurate, reliable, and flexible engineering and scientific data analysis capabilities. Furthermore, with the continuous development of cloud technologies, HPC technologies are gradually expanding to the cloud. However, HPC computing resources can be flexibly shared worldwide, and data privacy and security must be maintained.

FIGURE 11: DATA SECURITY AND PRIVACY MUST BE MAINTAINED IN THE AGE OF AI

SOURCE: FREEPIK

Traditional single-DC computing power cannot meet the future computing power requirements of AI. As a result, distributed AI based on cross-DC cloud computing power collaboration will become mandatory. Distributed AI can share data, schedule tasks across DCs, and maintain data privacy and security to improve computing speed and accuracy. In addition, AI computing power at the edge can process data more quickly and infer promptly, meeting the latency, security, and reliability requirements of industries such as autonomous driving and smart manufacturing.

AI will move toward intelligent cognition, and model parameters will number in the billions or even trillions. AI big models will drive computing architecture innovation.

COMPUTING SERVICE SCENARIOS ARE ENRICHED

A computing network responsible for intercomputing and user computing must provide network capabilities in bandwidth, latency, reliability, and security for different service scenarios. For example, model-training scenarios require ultra-large bandwidth and deterministic latency to securely transmit 10s of terabytes or petabyte-level sample data to computing nodes across WANs within a specified period. This requires a computing network with 10s of terabytes of bandwidth per fiber, deterministic latency, flexible scheduling, zero packet loss, and necessary encryption capabilities. On the other hand, scenarios such as VR real-time rendering, self-driving, and industrial control require a computing network with millisecond-level ultra-low latency, 99.999% reliability, and high security. Therefore, carriers must implement end-to-end optimization and upgrade existing access networks, metro networks, and backbone networks to achieve networking architecture and topologies, link bandwidth, latency, reliability, agility, and security to meet emerging computing power service bearer requirements.

CLOUD NETWORK KEY ARCHITECTURE AND TECHNOLOGICAL INNOVATIONS

As already discussed, the digital economy and 5G are driving unprecedented changes in service providers' networks. Network modernization is necessary to meet the heightened expectations of consumer and enterprise customers. As a result, enterprises or at-home clients will pay higher prices for superior performance and deterministic user experiences.

A high degree of cloud-network convergence is desirable for unified transport bearer networks. As a result, IP functionality is optimally delivered with best-of-breed routing capabilities, while optical systems must be massively scalable for cloud networks. Therefore, future IP and optical bearer transport networks must support the following key attributes or capabilities:

- Greater network scalability
- Enhanced network intelligence
- Always-on with enhanced network robustness
- Simplified, delayered, and integrated
- Congestion-free, deterministic performance
- Ultra-high reliability, anti-multiple-fiber cuts
- Multilevel latency circle, meeting cold, warm, and hot data requirements

CLOUD-NETWORK CONVERGENCE SPANS FOUR KEY SCENARIOS

The four scenarios for underlay transport networks to support cloud-network convergence are discussed below.

CLOUD ACCESS NETWORK

This is mainly for a connectivity solution that enables cloud edge terminals to support multiservice access and to access uplinks to private cloud networks through the era of gigabit/10G digital home broadband and 5G / 5G Advanced or 6G.

CLOUD PRIVATE NETWORK

This scenario firmly supports differentiated and deterministic user experiences through IP private lines and high-end premium optical private lines in the B2B digital era. Through its minute-level elastic scaling, IP private-line solutions and FlexE-enabled hard network-slicing technology are mainly used for SMEs. In some scenarios, it covers schools and simple healthcare facilities. Optical fiber, with its millisecond-level and ultra-low-latency capabilities, is mainly used to support guaranteed service levels for industries such as government, finance, and healthcare.

CLOUD BACKBONE NETWORK

This scenario is built explicitly for a backbone network for connecting to cloud and internet data centers, leveraging the capabilities of IPv6 Enhanced, SRv6, 400G/800G IP, and wavelength-division multiplexing (WDM) and intelligent path computations to deliver flexible multicloud access.

INTELLIGENT ALL-OPTICAL NETWORKS

This solution, through optical cross connects (OXC), metro OTN, backbone OTN, optical access network, and all-optical smart operation technologies, features a low-latency, ultra-high reliability cloud network foundation to provide high-bandwidth and low-latency ultra-high reliability connectivity for express tra c transiting network routers and to avoid unnecessary consumption of router resources.

SERVICE PROVIDERS' INCREASED CHALLENGES IN BUILDING CLOUD-NETWORK CONVERGENCE

Clients' expectations of their experience are rising with the development of emerging applications, translating into higher-performance services. As a result, service providers look to maximize their higher revenue streams and manage their profit and loss while modernizing their IP and optical-enabled cloud-network convergence.

The following are the overall existing network challenges in building the foundation of cloud-network convergence:

- The operational costs of brownfield aging networks concerning processing, power, and space requirements are rising.
- Multiple transitions and hops from one ring to another are prone to higher latencies and throughput times.
- The existing network supports significantly smaller client bandwidths and is unsuitable for cloud network integrations.
- A fast cloud and slow network and isolated clouds and networks mean slow provisioning.
- Multicloud access is complicated and difficult because in the existing network infrastructure there is one connection to one cloud.
- Express traffic transiting network routers results in unneeded consumption of router resources.
- Siloed separate IP and optical network management systems have limited ability for end-to-end service management and orchestration.
- There is a lack of multi-tenant operation capabilities.
- There is a lack of end-to-end integrated managed security collaboration.

DEVELOPMENT PRINCIPLES OF THE TARGET CLOUD-NETWORK CONVERGED TECHNOLOGY ARCHITECTURE

Cloud-network convergence is an inevitable trend for developing new digital information infrastructure. However, irrespective of any scenario solution discussed above, the underlying concrete principles remain the same for the development of cloud-network convergence or integration:

- **Network as the foundation.** An open, agile, convergent, and secure intelligent IP and optical network provides a ubiquitous intelligent bearer and ensures the foundation of the new high-capacity, high-performance, and highly reliable cloud network information digital infrastructure.
- **Cloud as the core.** Cloud is the carrier and core of the new digital information infrastructure, providing resources and capabilities for big data, the IoT, AI, 5G/6G, gigabit/10G fiber networks, and all IP and optical networks.
- **Network moving with the cloud.** The NaaS characteristics of new agile and open IP and optical networks should make it possible to automatically carry out flexible adaptation and on-demand deployments according to the demands of the cloud, thus forming a network model actively adapting to the cloud and contributing to the virtualization of cloud network end-to-end capability.
- **Integration of cloud and network.** Unified, integrated cloud bearer network resource and service capability breaks the physical boundaries of the traditional cloud and network and forms an integrated convergent technology architecture.

KEY NETWORK CAPABILITIES FOR A SUCCESSFUL TARGET CLOUD NETWORK ARCHITECTURE

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 networkwide connection, one-click fast scheduling, one-fiber multipurpose transport, and a one-stop unified end-to-end security mechanism.

Let us look at the six dimensions the cloud era demands from integrated intelligent IP and optical bearer networks.

NETWORK PERFORMANCE

The basic network performance of the network to support cloud services is measured by network coverage, network bandwidth, and other key indexes:

- **Network coverage:** includes wired/wireless network coverage, which will meet the requirement for extension and expansion of the cloud to the edge, ensuring “where there is cloud, there is a network”
- **Network bandwidth:** flexible network bandwidth adaptation and sufficient network bandwidth assurance, which may be called by the cloud at any time to satisfy demand
- **Network latency:** promised latency capability from the metro network to the backbone network, constructing multilevel latency circles to meet differentiated access requirements of hot, warm, and cold data in various industries

NETWORK AVAILABILITY

Refers to the ability of the network to continuously provide reliable connection services for cloud services, mainly including differentiated SLAs and assurance:

- **SLA assurance:** the provision of high-quality assurance for high-level services to meet the customer’s specific requirements for network quality
- **Differentiation assurance:** differentiated connection service for cloud services and multiple service levels through technologies such as multilayer redundancy and backup, multiple routing, quality of service (QoS) mechanisms, and dynamic resource scheduling

NETWORK INTELLIGENCE

The capabilities of traditional networks need to be enhanced in terms of network intelligence to meet the flexible and ever-changing demands of the cloud, including network scalability, programmability, rapid fault discovery and automatic traffic switching, dynamic optimization of global network resources, and so on:

- **Elastic scalability:** network coverage, bandwidth and other performance may be adjusted and scaled up or down to meet customer and service requirements.
- **Closed-loop automation:** a closed loop of network operators achieves automatic provisioning, fault location, and troubleshooting, reducing manual operational interventions and improving network performance.
- **Network programmability:** the network services may be programmatically described and implemented in terms of protocol, performance, function, coverage, and so on.
- **Rapid fault discovery and automatic traffic switching:** faults may be quickly located and the load switched automatically to ensure stable network performance and to avoid affecting the customer experience.
- **Dynamic optimization of end-to-end network resources:** network resources may be dynamically optimized in real time according to the cloud service demands, user access, and other factors.

FLEXIBLE ADAPTABILITY

The network capability services can be configured and terminated in a one-stop manner, with the type, function, and performance of the services—including rapid provision, atomic capability virtualization, and integrated network supply—capable of being easily modified and changed:

- **Rapid provision:** starting from the demand for cloud, automate the deployment and opening of network resources, and realize the integrated provision of cloud network resources, saving the service provisioning time to the greatest extent.
- **Atomic capability virtualization:** network capabilities can be disassembled into atomic capabilities, and these can be combined and orchestrated to be invoked by cloud services through unified encapsulation.
- **Integrated network supply:** this presents the cloud with a configurable, adjustable, quality-assured integrated network rather than fragmented network elements and connections.

NETWORK SECURITY

Network security refers to the end-to-end integrated security assurance of the network provided for cloud services, including address and identity security, protocol security, and identity security:

- **Address and user identity security:** access controls are in place to identify and block malicious addresses and ensure the authenticity and credibility of addresses and identities. Network access control and other measures are adopted to achieve user identification, traceability, and behavior audit to ensure the authenticity and credibility of user identity.
- **Protocol security:** cryptographic technology is used to ensure the integrity, legality, and confidentiality of data in the communication group, thereby ensuring the security of communication data and network protocol.

NETWORK SUSTAINABILITY

To meet the requirements of future sustainable development, cloud network architecture should be green and sustainable with regard to environmental friendliness, energy efficiency, and resource recycling. Net zero carbon emissions are the benchmark for all the underlay routing and optical chassis:

- **Environmental friendliness:** cloud network architecture should consider the reduction of energy consumption and carbon footprints, for example, through the use of low-power devices and renewable energy and the optimization of data center design.
- **Energy efficiency:** cloud network architecture needs to improve energy utilization efficiency, for example, by using intelligent energy management systems and efficient hardware devices.
- **Resource recycling:** cloud network architecture must consider how to recycle and reuse resources, for example, reusing old devices and the heat energy of data centers.

THE ENDURING VALUE OF INTELLIGENT IP AND ALL-OPTICAL TECHNOLOGICAL INNOVATIONS FOR CLOUD-NETWORK CONVERGED INFRASTRUCTURE

This section delves deeper into holistic upgrades of IP and optical networks and essential technological innovations for cloud-network converged or integrated infrastructure.

CLOUD-NETWORK CONVERGENCE REDEFINING IP NETWORKS

Network connectivity is essential to the success of the digital economy; the trend of an entire IP network is irresistible. Data communication IP networks, abbreviated as networks (including campus networks, WANs, data center networks, etc.), represent networks' logical evolution.

The IP bearer networks will not be expected to simply support simple traffic flows as in the past but to keep cloud-network convergence that enables ultra-reliable low-latency communications. Use cases include intelligent manufacturing, smart grids, cloud VR/AR, and metaverse smart grids. Moreover, the diversification and magnitude of network service requirements from 2025 onward will create substantial new market potential, which will required robust IP network infrastructure.

The three fundamental catalytic driving forces in the IP network evolution are as follows:

- **AI drives the evolution of unified networking for computing and storage resources and flexible cross-domain scheduling.** This may be achieved by end-to-end IPv6 Enhanced and SRv6 networking, realizing fully intelligent cloud-network synergy.
- **The metaverse and cloud VR demand upgrade of network bandwidth.** Immersive applications such as the metaverse further drive network bandwidth upgrades. The demand for assurance in end-to-end, multiservice, slice-level SLAs is also becoming an essential part of the user experience journey.
- **Industrial digital transformations are increasing the complexity of demand.** This drives networks to provide one-hop simplified access to multicloud, heterogeneous IoT access, and end-to-end deterministic networking capabilities, enabling cloud edge device collaboration and an intelligently connected industrial internet.

HOLISTIC UPGRADE SUGGESTIONS FOR IP BEARER NETWORK INFRASTRUCTURE FOR CLOUD-NETWORK CONVERGENCE

Growth in the digital economy catalyzes IP access, aggregation, and core network bandwidth roadmaps. Therefore, the end-to-end transport network from IP edge to backbone needs a holistic upgrade to meet the full cloud-network converged transport infrastructure requirements of open RAN, C-CRAN, and V-RAN:

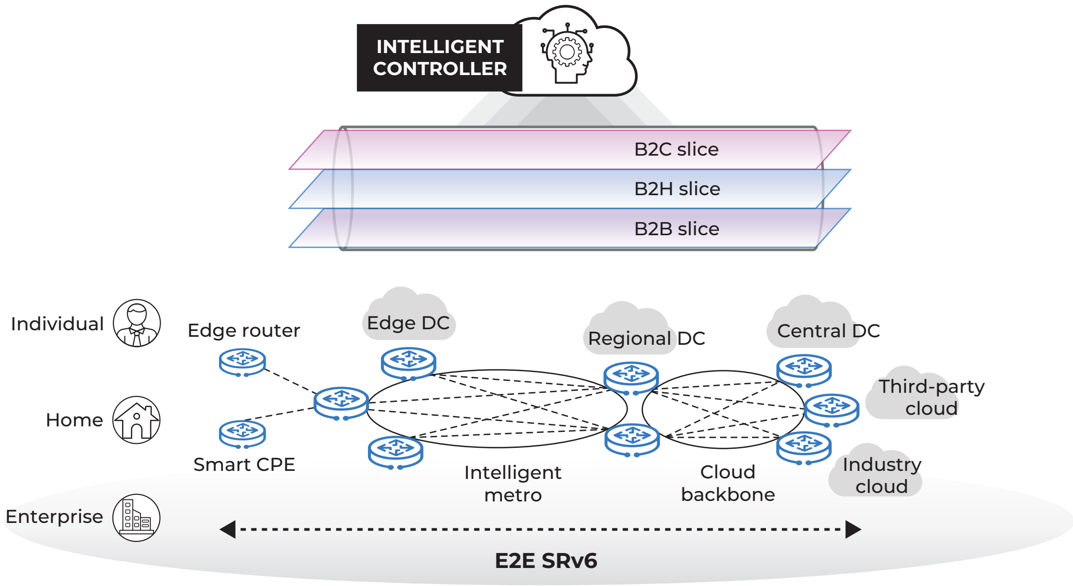
- Converged edge for unified RAN access, 50GE site, and 100GE uplink
- Full-service converged metro with 100GE downlink and 400GE uplink
- Full-service converged core for 800GE interconnections with zero packet loss and low-latency architecture
- End-to-end SRv6, telemetry, tenant-level slicing, and the entire network automation lifecycle
- Upgrade of the data center network or data center interconnect networks (DCNs) to provide IT-related services for the IP private-line services to enterprises and vertical industries
- Realizing all-ethernet converged network infrastructure with full lifecycle automation
- Generalized computing power to AI-enabled computing power
- Layer 4 autonomous and predictive self-driving networking for multicloud interconnection
- Ensuring a deterministic IP networking experience with improvements in low latency for IIoT for mission-critical applications in DCNs.
- A reduction in static delay in DCNs from 1 microsecond to 200 nanoseconds.
- Scalable and technology-driven advanced Dragonfly topology, enabling DCNs at a scale of a million servers
- Network jitter improvement from milliseconds to microseconds, with reliability reaching the industry-demanded level of 99.9999%

KEY TECHNOLOGICAL INNOVATIONS OF IPV6 ENHANCED END-TO-END SRV6 NETWORKING CAPABILITIES FOR CLOUD-NETWORK CONVERGENCE

Solving IPv4 address depletion means adopting IPv6-based connectivity, which is imperative in the digital era. IPv6 is the foundation, and IPv6 Enhanced (with AI capabilities) allows for new service innovations and unleashes intelligent network connectivity. However, today's networks cannot unleash the cloud-network synergy to meet 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.

As shown in **Figure 14**, IPv6-based IETF protocol innovations aim to fine-tune IPv6 functionalities defined in IETF and help build an enhanced, large-scale IPv6 network. For example, IPv6 Enhanced with SRv6 (segment routing) protocol ensures simplified and unified end-to-end IP addressing and tunneling signaling capabilities, reaching data centers, end systems, and campus networks and reducing cross-domain conversions. It also offers a better-sliced performance by ensuring low latency and less round-trip time, thanks to the elimination of network address translation requirements. In addition, IPv6-enhanced technological innovation refines the integrated intelligent IP bearer cloud-network convergence to help carriers explore the business value of at-home connections, build new digital business models, and accelerate the digital transformation of industries.

FIGURE 14: INTEGRATED IPV6 ENABLED INTELLIGENT CLOUD NETWORK



SOURCE: OMDIA

IPV6 ENHANCED WITH END-TO-END SRV6

IPv6 Enhanced with end-to-end SRv6 ensures increased reachability, simplified networking, and network programmability, marking a landmark evolution in IP network history. SRv6 cost-effectively takes traffic engineering beyond the MPLS era, enabling robust SLAs and programmability with the following capabilities:

- End-to-end SRv6 ensures application/computing awareness
- Upgrading tenant-level network slicing granularity from the 1,000 level to the 100,000 level

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 allow 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; new end-to-end 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.

IPv6 Enhanced can help accelerate the commercialization of new Industry 4.0 use cases in smart transport, mining, and manufacturing by creating on-demand and capillary networking through the combination of IPv6 address space for IoT devices with IPv6-based network slicing, AR/VR, and other technologies. The benefits of these smart industries include higher efficiency and safer work environments.

Introducing AI advances allows operators to drastically reduce fault location times and automate operations and maintenance activities.

SRV6 INNOVATION

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 end-to-end unified protocol and SRv6 achieve zero packet loss and 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 brings the demand for intelligent connections, industrial automation, and immersive experience.

IPv6 Enhanced network and AI-enabled automation are 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.

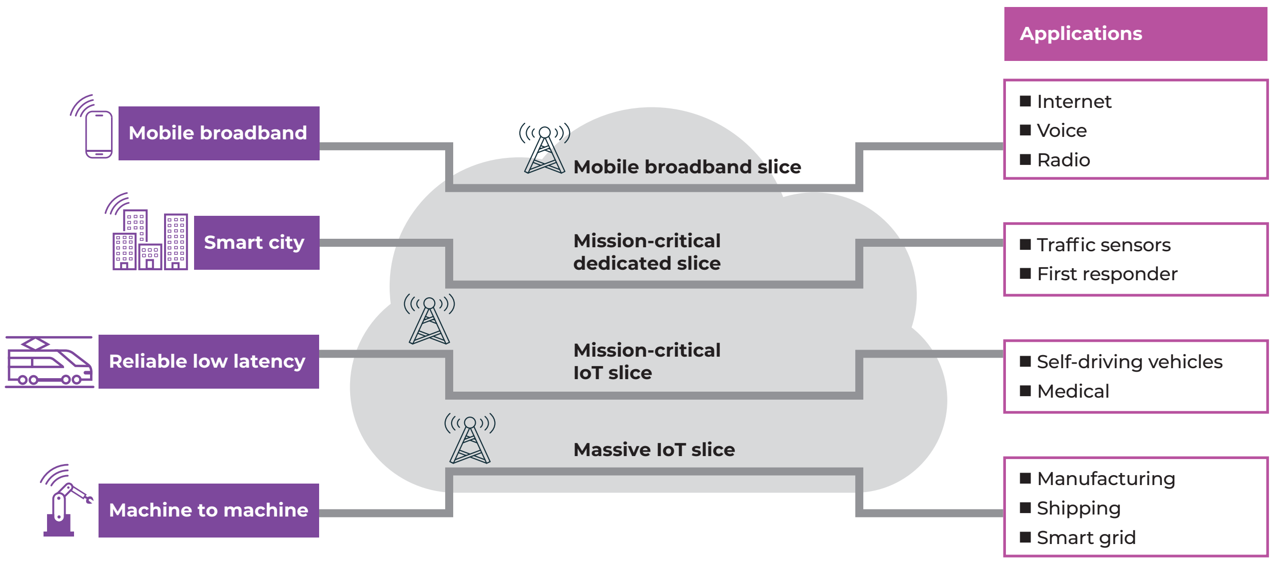
When applied to networking, AI combines machine learning, analytics, and automation. AI is not unique to IPv6, but applying AI to IPv6-based networks allows service providers to take full advantage of the massive scale the protocol provides as it is applied to increasingly complex networks. With the help of AI, IPv6 networks can expand opportunities in 5G, private-line service, home broadband, and other applications such as IPv6-based intelligent routing, network fault analysis, root cause analysis and positioning, self-healing and prediction, network resource arrangement and management, and IPv6 intelligent security. Although AI itself is new to networking, much of the future of AI as applied to IPv6 is yet to be defined.

In addition, full SRv6 and BIERv6 encapsulation for packet multicasting (BIERv6) shorten provisioning times to match the requirements of cloud application. This intelligent cloud-network synergy requires the proactive inclusion of simplified IPv6-only reachability and unified forwarding across all IP network domains with no additional signaling requirements. Therefore, this cloud-delivered synergy will transform IP edge, traditional device-centric metro networks, and core networks into modern IP networks.

SLICING

It is true that bearer network FlexE-enabled hard slicing has value as a “magic wand” to support new stringent latency-sensitive service demands. Though slicing is not a new concept for the telco world, the real potential value of slicing is now fully unlocked. By logically slicing a single physical infrastructure, end-to-end network slicing makes it possible to address various operational service needs . As shown in **Figure 15**, end-to-end network slicing will be crucial for operators in enabling them to offer the full spectrum of 5G use cases, including a mix of ultra-reliable low-latency communications (URLLC), massive machine-type communications (mMTC), and Enhanced Mobile Broadband (eMBB).

FIGURE 15: TRANSPORT BEARER NETWORK SLICING



SOURCE: OMDIA

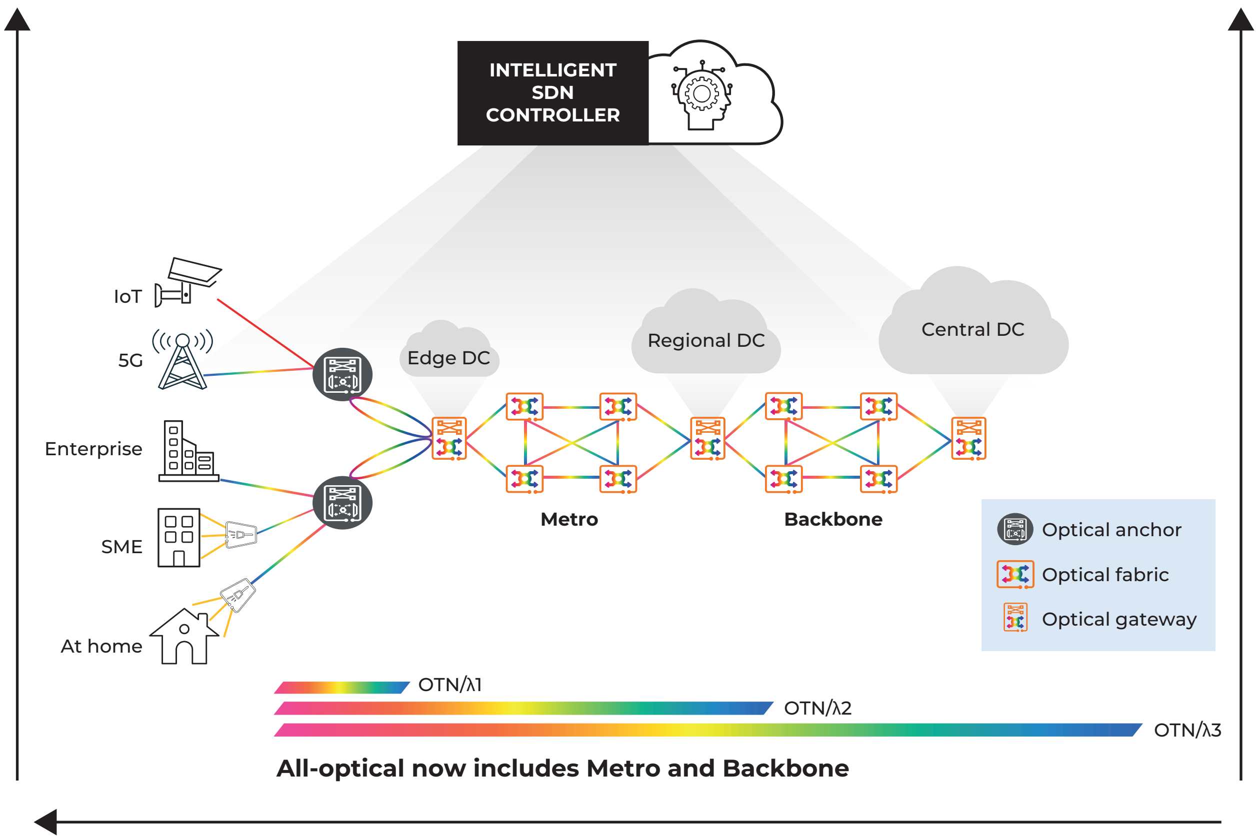
In cloud-network convergence infrastructure, an IP bearer network that bridges RAN and core with end-to-end network slicing by virtualizing the physical hardware resources for low-latency intelligent and smart services is an essential requirement and a revenue generator. Haptic (tactile) internet, smart logistics, smart cranes, and smart hospitals offer excellent examples of stringent SLAs for delivering the best user experience. Moreover, even big industrial private enterprises want to leverage cross-domain network-slicing capabilities in an ever-expanding 5G ecosystem.

REDEFINING ALL-OPTICAL NETWORK FOR CLOUD-NETWORK CONVERGED BEARER INFRASTRUCTURE

Enterprise and home broadband users need cloud-network convergence for convenient access and flexible, agile, secure, and reliable network capabilities to access the cloud. Intercloud interconnection requires ultra-large-capacity and ultra-low-latency network capabilities. Cloud-network synergy integration requires network resource visualization, large-scale network management and control, and integrated cloud network orchestration capabilities.

As shown in **Figure 16**, the existing optical transmission network should be developed in the direction of ultra-high bandwidth, ultra-low latency, security and reliability, ubiquitous coverage, flexible agility, and intelligent management and control.

FIGURE 16: ALL-OPTICAL TARGET NETWORK ARCHITECTURE



SOURCE: OMDIA

HOLISTIC UPGRADE SUGGESTIONS FOR ALL-OPTICAL BEARER NETWORK INFRASTRUCTURE

The architecture and transmission capabilities of the optical network should be comprehensively upgraded to build an all-optical target network architecture with ubiquitous coverage. In addition, the end-to-end all-optical bearer transport network needs a holistic upgrade to meet the full cloud-network converged transport infrastructure requirements:

- An upgrade to 400G/800G backbone network with a single-fiber capacity of 32TB/64TB and 800G-plus metro ultra-high-speed network to meet ultra-high-bandwidth guarantees
- All-optical switching capability from metro network to backbone network to achieve ultra-low latency for specialized industries' premium private lines, some high-quality services such as AR/VR, intercloud interconnection, and so on
- One-click collaborative faster provisioning of optical and electrical links within minutes
- Differentiated links automatically constructed based on service quality
- Flexible hard pipes to meet the requirements of hard isolation and bearing of services in different industries
- Supporting continuous service availability against multiple fiber cuts as a benchmark for the achievement of availability of 99.999% or better
- Real-time detection of service traffic changes and automatic link bandwidth adjustment as an essential requirement for end-to-end visualization and "intelligentization" traffic awareness
- Cloud pool awareness to obtain cloud pool location and resource information and automatically allocate appropriate nodes and resources based on service requirements
- Multifactor path computation and service provisioning in the cloud
- Visualized energy consumption of networkwide nodes for all-optical network visualization
- Visualization of deployment location of cloud pool nodes on the entire network, based on GIS; visualization of the geographical coverage of each cloud pool based on the time delay necessary

KEY TECHNOLOGICAL INNOVATIONS OF ALL-OPTICAL NETWORKING CAPABILITIES FOR CLOUD-NETWORK CONVERGENCE

The all-optical target network architecture has three network function nodes: optical anchor, optical grooming node, and optical gateway:

- The optical anchor is the ingress node of the access quality all-optical network, referred to as optical access (OA) for short. One hop can be configured directly to the optical gateway through the optical network to enable users to access cloud nodes at all levels.
- Optical fabric (OF) implements nonblocking and flexible grooming of service traffic on an all-optical network. Based on the grooming object type, optical grooming nodes can be classified into optical-electrical hybrid grooming nodes and all-optical grooming nodes to configure optical-layer connections quickly.
- An optical gateway is the ingress from cloud resource pools to all-optical networks, referred to as optical edge. They can be deployed on the metro, provincial backbone, and national backbone networks to implement cloud access for end users and high-quality interconnection between cloud resource pools.

Some suggestions for key technological innovation implementation of all-optical networking capabilities for cloud-network convergence are as follows:

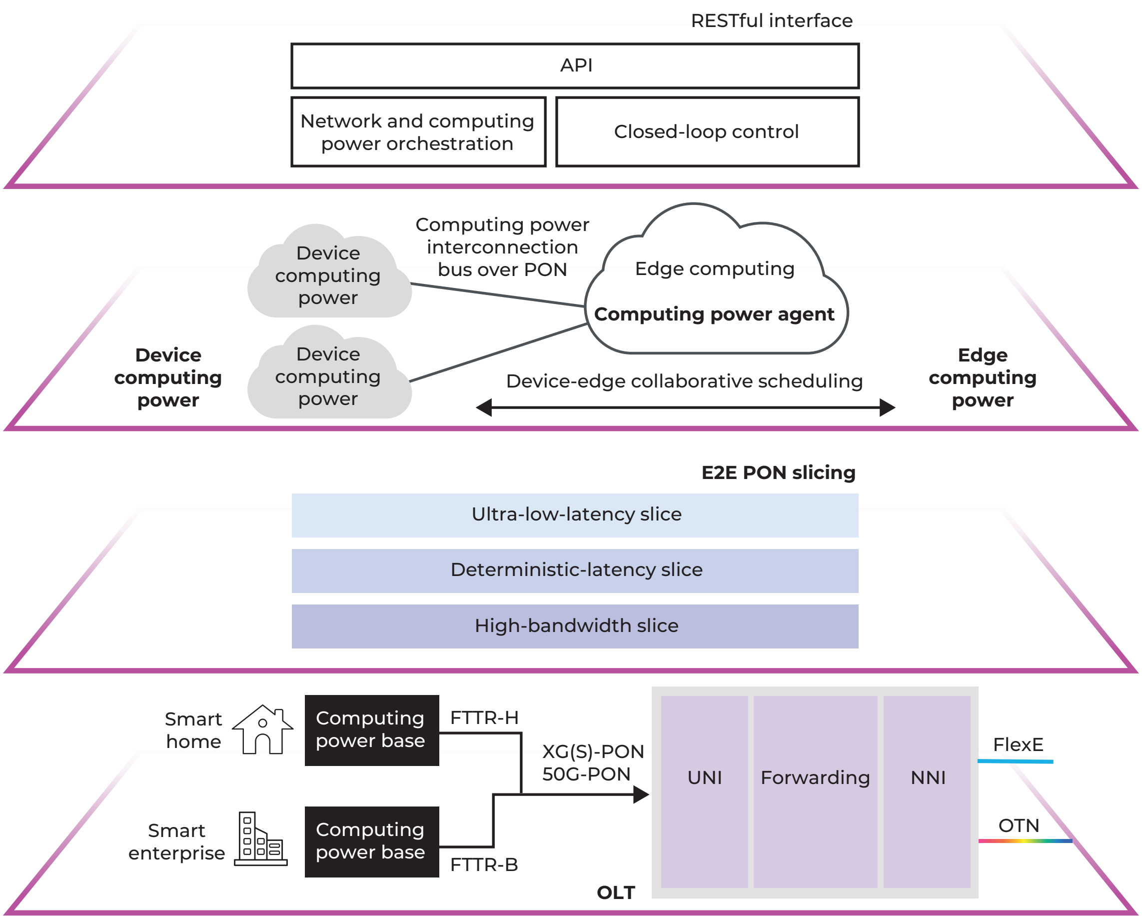
- Continuous high security and reliability enhancement required for cloudification of government and enterprise core systems
    - Hard slicing at the wavelength level (λ) and electrical-layer timeslot level (ODUk)
    - Optical & electronic protection coordination capability, such as ASON, SNCP, and so on.
- All-optical switching and latency-based link planning to build ultra-low-latency, all-optical networks
    - Delay-based network planning
    - High- and low-dimensional OXC
- A crucial ability for ultra-high speed
    - 400G/800G C+L technology
    - New optical-fiber technology

- Growth in industry digitalization as a catalyst for the optical access network to improve coverage capability
  - OTN all-optical access technology
  - Low-cost WDM access technology
- Service awareness and optical and electrical collaborative scheduling for an agile experience with cloud services
  - Flexible service awareness capability
  - Flexible optical and electrical scheduling capability

ULTRA-BROADBAND OPTICAL ACCESS AND HOME NETWORKS

Ultra-broadband optical access and home networks make virtual immersion (referring to anything from VR and AR to MR) a reality in the metaverse era. Bandwidth is an essential feature of the future network and will be continuously upgraded in the next decade. At-home consumers appear to be ambitious to unleash this immersive experience for their remote-control gaming, VR cloud systems, virtual entertainment, education, human-to-human interactions, human-to-machine interactions, and more. Therefore, the optical access network must be upgraded to NaaS. As shown in **Figure 17**, the optical access network architecture for cloud-network convergence consists of the following four layers from top to bottom:

FIGURE 17: FOUR-LAYER ALL-OPTICAL ACCESS NETWORK



SOURCE: OMDIA

- **Management, control, and analysis layer.** This layer performs access network control and data parsing. It provides unified service-based interfaces and processes user service requests through network orchestration based on end users' or ICPs' customizations. In addition, it can monitor and parse the computing power, services, and device data and running status on the network in real time and perform optimization and closed-loop management based on the data and status.

- **Computing layer.** The optical line terminal (OLT) and FTTR functions as a compute node to provide computing service interfaces for external systems in a unified manner. Within the node, the heterogeneous computing power of the OLT and FTTR is orchestrated and scheduled in a unified manner through the internal interfaces of the OLT and Passive Optical Network (PON) physical links to form a computing power plane, providing nearfield and onsite computing services for smart home and smart enterprise services. This layer also provides differentiated SLA measurement and assurance services for the service layer.
- **Service layer.** At this layer, based on the highly reliable OLT and FTTR devices and SLA requirements of users, an end-to-end SLA and resource isolation and assurance solution is formed, including Wi-Fi anti-interference, low latency, bandwidth assurance, and resource isolation and assurance within FTTR devices; PON link bandwidth, latency, and isolation and assurance; and forwarding resource isolation, service QoS, and low-latency channel assurance inside the OLT. The OLT connects to the metro network in the upstream direction by overlaying SRv6/VxLAN tunnels or underlying OTN pipes.
- **Device layer.** This layer is the infrastructure of an access network. To meet the computing power and service requirements, XG(S)-PON/50G ONO LT devices are typically used to provide 1Gbps or higher access bandwidth, low-latency, and low-jitter PON capabilities for each user. In addition, FTTR-H/FTTR-B terminals are used to realize optical+Wi-Fi collaborative scheduling and optical compensation for Wi-Fi to eliminate performance deterioration caused by Wi-Fi wall penetration, reduce Wi-Fi latency from over 10ms to less than 1ms, and support seamless roaming between different Wi-Fi APs.

KEY TECHNOLOGIES

To support cloud-network convergence, optical access and home networks require research and evolution on the following key technologies.

SLA MEASUREMENT

In-situ Flow Information Telemetry (IFIT) is an in-line detection technology based on actual service flows. Introducing this technology allows an optical access network to provide end-to-end and hop-by-hop service-level (packet loss, traffic, latency, and jitter) measurement capabilities for actual service flows, quickly detect network performance faults, and accurately demarcate and rectify faults. Compared with traditional detection technologies such as Two Wire Active Measurement Protocol (TWAMP) and Y.1731, IFIT has more networking flexibility, SLA accuracy, and fast fault demarcation advantages. IFIT is an essential method for future network O&M.

SLA ASSURANCE

With the integration of AI, an optical access network can detect services and scenarios in real time and support dynamic allocation and real-time intelligent scheduling of Wi-Fi, PON, QoS, and forwarding resources, achieving deterministic SLA assurance and premium service experience. Critical technologies for SLA assurance include smart Wi-Fi, smart DBA, smart QoS, and smart forwarding. Smart Wi-Fi detects real-time Wi-Fi service scenarios and air interface environment changes, including the application type and load, AP networking topology, STA location, and interference matrix. Through AI algorithm inference and parameter optimization, smart Wi-Fi dynamically schedules air interface resources based on service SLA requirements to improve Wi-Fi spectrum utilization, avoid and tolerate interference, and guarantee differentiated Wi-Fi experience in different services.

Smart DBA detects service traffic changes in the PON upstream direction in real time, trains DBA bandwidth usage and latency models based on historical periodic data and packet size learning, establishes an optimal bandwidth allocation model, and intelligently adjusts DBA policies to provide a differentiated experience for users in different scenarios and reduce the deterministic scheduling latency.

Based on application awareness and scenario awareness results, smart QoS learns and generates service QoS policies based on service requirements for bandwidth and latency, dynamically optimizes and delivers QoS policies, and provides different QoS policies for traffic forwarding for different services and applications.

Based on application and scenario identification results, smart forwarding intelligently selects application traffic forwarding channels (such as the internet, education/office acceleration, and cloud gaming / cloud VR channels) to provide differentiated policy-based routing for services with different SLA requirements.

SLICING

SLA assurance is meaningful only when it is performed in an end-to-end manner. Therefore, slicing must also be performed from end to end on a network:

- **Wi-Fi air interface slicing:** Wi-Fi 6 resource units (RUs) are sliced and provided to specified services in fixed or dynamic mode to implement exclusive, preferential, and best-effort air interface resource usage, thereby implementing differentiated bearing for service slices.
- **PON network slicing:** optical network terminal (ONT) slices are divided based on WAN ports and allocated to services identified by IP addresses. In the upstream direction, the PON network uses DBA to allocate upstream bandwidth using T-CONTs in fixed, assured, or best-effort mode to implement exclusive, preferential, and best-effort upstream bandwidth usage. To meet the requirements of low-latency service slices, extra registration/ranging channels are introduced in a time-division multiplexing (TDM) PON system to eliminate the extra latency and jitter caused by registration/ranging windows of regular service channels.
- Furthermore, a single-frame multiburst technology is used to increase the timeslot and send times for uplink scheduling of an optical network unit (ONU) in each frame, thereby reducing the latency. Thanks to these low-latency technologies, the maximum latency introduced by a PON system can be reduced from milliseconds to 200 microseconds. In the downstream direction, the OLT PON ports use traffic scheduling technology based on resource reservation to implement differentiated bearing.

OLT FORWARDING PLANE

The dual plane switching architecture provides a better solution for slicing scenarios. After being reassembled by the PON MAC, low-latency packets can be fragmented and switched to the TDM upstream board through the low-latency switching plane. The OLT network side supports IP+TDM dual upstream transmission to interconnect with the IP metro and transport networks. The rigid channels of the metro transport network ensure low latency, jitter, entire bandwidth, and high security. On the TDM forwarding plane, 2Mbps–100Gps exclusive hard slicing is implemented. The IP metro network ensures network efficiency and provides high-bandwidth bearer capabilities for services insensitive to latency and jitter. High QoS channelized sub-interfaces are used to implement preferential and best-effort soft slicing. Dynamic slicing and SLA closed-loop technologies used in slice lifecycle management can significantly improve operational efficiency.

DYNAMIC SLICING TECHNOLOGY

After detecting that an ONT is powered on, the OLT instructs the control plane to select a service node and route. After selecting a service node, the OLT selects an IP or OTN path based on the service and user SLA requirements. After selecting a node and path, the control plane configures the network and service layers. When a user starts to use an application, the OLT identifies the application. An application that needs to be accelerated triggers path optimization on the control plane. The control plane selects the optimal path to bypass the metro network, for example, by selecting a virtual private network (VPN) or OTN acceleration.

REAL-TIME SLA MONITORING AND SLICE SLA DYNAMIC CLOSED-LOOP TECHNOLOGY

The OLT identifies applications, monitors application service quality, makes decisions on slice resources that need to be adjusted in real time, and adjusts slice resources at short periods. For slice resources that do not need to be adjusted in real time, the management, control, and analysis layer makes decisions and adjusts the resources to ensure the slice service level.

APPLICATION AND TERMINAL IDENTIFICATION

- **Terminal identification:** by the detection of characteristic information in packets, including MAC, HTTP UserAgent, DHCP Option, LLDP and mDNS, a terminal identification library is generated. Based on big data and AI identification models, the terminal type, vendor, model, and operating system (OS) characteristics can be identified in real time from multiple dimensions, providing a data foundation for differentiated SLA assurance for different terminals.
- **Application identification:** the corresponding application can be identified by detecting characteristic information in packets, including traditional 5-tuple information and application-layer information such as specific character strings or bit sequences. The characteristics of some application protocols are reflected in a single packet and distributed in multiple packets. In this case, multiple packets must be collected, and their characteristics must be associated to identify the application. A multidimensional identification model is established to update the identification algorithm dynamically based on application characteristics.

COLLABORATIVE SCHEDULING OF OPTICAL LINK AND WI-FI RESOURCES

The core concept of an FTTR network is the collaborative scheduling of optical link and Wi-Fi resources to achieve the effect of one FTTR network and provide a deterministic user experience. The master FTTR unit manages and controls the entire FTTR Wi-Fi network centrally. In this way, Wi-Fi air interface resources are scheduled in an orderly manner, reducing the Wi-Fi forwarding latency and improving the Wi-Fi performance of the entire FTTR network. The FTTR network centrally manages and controls Wi-Fi resources, implementing Wi-Fi roaming and imperceptible handover. In the single FTTR Wi-Fi network architecture, the master FTTR unit allocates air interface resources to all slave FTTR units through an optical link with ultra-low latency to ensure orderly air interface access and to eliminate Wi-Fi uplink and downlink conflicts on the entire FTTR network.

The master FTTR unit also intelligently identifies services and allocates Wi-Fi air interface timeslots based on service priorities to ensure the access experience of high-priority services. Optical links' uplink and downlink bandwidth scheduling is deeply integrated with the Wi-Fi air interface resource scheduling. The optical link bandwidth allocation algorithm is dynamically adjusted based on the Wi-Fi air interface status. In this way, after the FTTR downlink data reaches a slave FTTR unit through the optical link, it is immediately sent through the Wi-Fi air interface of the slave FTTR unit. After receiving uplink Wi-Fi air interface data, a slave FTTR unit immediately sends the data to the master FTTR unit through the DBA window allocated for the optical uplink, implementing collaborative scheduling of optical link and Wi-Fi resources.

Imperceptible roaming handover is based on the collaborative scheduling of optical links and Wi-Fi resources. The master FTTR unit obtains the Wi-Fi configuration and topology information of the entire FTTR network through low-latency optical links, manages and controls connections of all terminals in a unified manner, uses intelligent algorithms to determine the next slave FTTR connect to roaming terminals quickly, and switches the Wi-Fi connection and data forwarding at the same time. This dramatically reduces the roaming handover latency and ensures data interaction continuity.

KEY TECHNOLOGIES OF THE ULTRA-HIGH BANDWIDTH

- **The key technology of 50G PON:** the multi-PON module (MPM) coexistence solution of a single PON port on the OLT enables the 50G PON system and the PON system on the live network to coexist using optical distribution network (ODN) WDM. Currently, the G/10G combo solution is widely used. In the 50G PON system, the multiplexing function of GPON, 10G PON, and 50G GPON is built in the 50G PON combo optical module, which functions as a 50G PON combo port and a 50G PON combo optical module. In this way, different types of ONUs can be deployed on demand, and GPON ONUs, XG-PON ONUs, XGS-PON ONUs, and 50G PON ONUs can coexist on the same ODN. The downstream rate of the 50G PON system reaches 50Gbps. Three upstream rates are available: 50Gbps, 25Gbps, and 12.5Gbps. Different upstream rates can coexist through time-division multiplexing. However, DSP needs to be introduced to solve the problems of dispersion and high-bandwidth burst receiving.

- **Dispersion:** during the smooth evolution to 50G PON, the existing ODN network needs to be reused, and the link budget needs to be the same as that on the live network. For example, the link budget needs to be greater than or equal to 29dB for evolution in E/10GE PON areas and greater than or equal to 32dB for evolution in G/XG-PON areas. Compared with 10G PON, 50G PON increases the rate by five times, significantly reduces the receiving sensitivity, and increases the dispersion penalty after downstream 1,342nm transmission over 20km. Therefore, for 50G PON, the transmit power needs to be further improved, and oDSP needs to be introduced to improve the equalization and dispersion compensation capabilities and the receiver sensitivity.
- **Upstream high-bandwidth burst receiving:** the 50G PON system supports three upstream rates: 50Gbps, 25Gbps, and 12.5Gbps. Signals at different rates have different receiving requirements. The DSP technology is introduced to the OLT receiver to match linear BM-TIA components and implement 50Gbps high-bandwidth receiving. In addition, to better support TDM receiving at multiple rates, the DSP and MAC layers collaborate to optimize the burst reception performance on the OLT side.
- **Key technologies of Wi-Fi 7:** this is the 320MHz frequency band, supporting continuous 240 MHz, discontinuous 160+80MHz, continuous 320MHz, and discontinuous 160+160MHz modes. The 4096-QAM modulation mode increases the Wi-Fi PHY rate by 20% compared with the 1024-QAM modulation mode of Wi-Fi 6. In addition, multi-link, multi-RU, and preamble puncturing further improve the throughput and reduce the latency.

EDGE COMPUTING AND COMPUTING POWER SCHEDULING

Key technologies of edge computing and computing power scheduling in optical access networks include heterogeneous computing power platforms and OLT+FTTR computing power agents. OLTs and FTTR devices have various heterogeneous computing chips, including general-purpose CPUs, GPUs, FPGAs, NPUs, and dedicated AISCs. The edge computing platform encapsulates these heterogeneous computing chips to provide a universal container-based running environment, simplifying deployment. The computing power of an OLT and FTTR device is small, especially the computing power of an FTTR device. If the global server load balancing (GSLB) directly schedules the computing power of an FTTR device, the GSLB scheduling algorithm becomes more complex. A best practice is that the GSLB schedules only the OLT. The OLT connects to FTTR devices through a deterministic low-latency network and processes large computing tasks scheduled by the GSLB by cooperating with the FTTR device. In this case, the OLT schedules some computing power. That is why the OLT is also called a computing power agent.

CLOUD NETWORK INTELLIGENT EXPERIENCE MANAGEMENT AND NORTHBOUND SERVICE INTERFACES

During the digital transformation of cloud network services, the autonomous optical access network collects network data at high speed to detect the network infrastructure, network elements, network status, applications, and computing power and build data visualization capabilities for cloud network devices, connection status, Wi-Fi information, network traffic, service SLA, and computing power status. AI analyzes real-time cloud network service experience, builds service experience indicators, and restores network status in seconds based on data collection. Multidimensional models are used to locate network bottlenecks precisely. Technologies such as digital twin, knowledge graph, and machine learning are used together with perception, analysis, and decision-making to automatically discover root causes of faults and poor service quality, quickly rectify faults, and optimize poor service experience, improving network O&M efficiency. In addition, data programmability is supported in the northbound direction and quality-on-demand interfaces are built based on the latency, jitter, and throughput of applications. This provides an application experience data foundation for operators’ cloud network digital services, ensures real-time and dynamic optimization of cloud network service experience, and facilitates the promotion of the NaaS business model.

THE TECHNOLOGICAL INNOVATION OF CLOUD-BASED BROADBAND NETWORK GATEWAYS OR VIRTUAL BROADBAND NETWORK GATEWAYS FOR CLOUD-NETWORK CONVERGENCE

The increase in the number of at-home users with the rapid development of the emerging bandwidth-intensive applications UHD, 8K, and cloud VR poses daunting challenges for broadband network gateways (BNGs). A traditional BNG acts as a bridge in connecting many at-home subscribers to Layer 3 IP networks and their access and accounting authentication. These tightly coupled control and forwarding planes in traditional BNGs give rise to challenges of low resource utilization, complex management, difficulty in scaling, and limited flexibility and feasibility when the network expands and new services emerge. Thus, hard-to-manage services and slow service provisioning with a long time to market for new services with the ability to rectify issues in less time hinder true cloud-network convergence or adaptability within the cloud.

Cloud-based BNG or virtual BNG (vBNG) with CUPS (control plane and user plane separation) is cloud-native, fully virtualized software-based for greater network scalability, higher network performance, low cost, and higher network flexibility. VBNG operates on a “pay as you grow” model that saves service providers the upfront capex investment required to buy unneeded large BNG.

Cloud-based BNGs ensure the following benefits:

- Cloudification of the control plane allows for easier management and flexible capacity expansions.
- Control plane separations ensure a unified northbound interface for external systems and southbound interfaces.
- Unified address pool management allows for better user management and authentication.
- As a network edge, the user plane ensures user policy implementation and forwarding functions such as traffic forwarding, QoS, and so on.

INTELLIGENT IP AND OPTICAL O&M FOR CLOUD-NETWORK CONVERGENCE

With the rapid development of emerging enterprise, cloud, and home broadband VR applications, networks are becoming increasingly complex from an intelligent O&M perspective. This network complexity multiplies the O&M cost. To reduce this, a new whole-lifecycle and AI-enabled intelligent O&M method is required for IP and optical bearer networks. In addition, a fully autonomous driving network for end-to-end network automation is required.

DIGITAL MAP

A single digital map of all the network domains and layers is the key enabler to automating the infrastructure and service lifecycle. Optical and IP must act simultaneously to deliver redundancy and grant the service level requested by each connection flow through network slicing. A digital map of all the connection flow enables proactively preserving the service level needed by the specific service or customer by adequately measuring the status of each layer (e.g., optical, FlexE, SRv6 connection) underpinning the specific connection and relocating it in case of foreseen congestion.

Introducing AI and big data is the key to enabling the autonomous driving network. Thanks to these emerging technologies, the IP and optical networks will become intelligent for autonomous driving after cloud adoption.

THE TECHNOLOGICAL INNOVATION OF AI-ENABLED INTEGRATION FOR CLOUD-NETWORK CONVERGENCE

Data centers, campuses, and WANs 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 help in evaluating and measuring the advantages of autonomous network services; they also help facilitate the automation and intelligent transformation of networks and services. AI and big data technologies improve network planning, configuration, O&M, and optimization automation. In addition, autonomous driving networks (ADNs) also enable network automation and intelligence. Cloud-network convergence target network architecture aims at upgrading L3 (conditional autonomous) to L4 (highly autonomous) networks or, in later stages, to L5 for fully intelligent ADNs. ADNs 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, enterprises, and at-home users of VR, enhancing digitalization. ADNs use knowledge and data to drive three levels of intelligence, breaking the limits of manual processing. The three levels are:

- IP and optical network equipment intelligence
- Bearer network intelligence
- Service automation and intelligence

ADNs help to evolve network process automation from manual to intelligent and automatic decision-making to improve the overall IP and optical 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.

CONCLUSIONS AND RECOMMENDATIONS

The wave of digitalization brings excellent opportunities and challenges to service providers. High-quality physical cloud-network convergence as a target transport network infrastructure will be an inevitable trend that remains important for successful digitalization.

By 2025, 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 transport bearer network foundation with integrated secure devices to the cloud and automated network openness with on-demand multicloud interconnections and terminal capability enhancement.

The underlay transport bearer network architecture needs to be modernized and revitalized by ensuring the actual value of cloud-network convergence.

Moreover, the growth of the digital economy is catalyzing bearer network access, aggregation, and core network bandwidth roadmaps.

RECOMMENDATIONS: A WAY FORWARD

- A service provider's cloud-based digital transformation charter should adopt cloud-network convergence, not simply cloud-network connection, as a key vision.
- Cloud-network convergence is a future development trend of information infrastructure that should not be changed.
- Timely adoption of intelligent cloud-network synergy initiatives or convergence will help DSPs meet the complex demands of network agility, efficiency, and scalability and inspire new growth.
- Unleashing an intelligent cloud network to inspire new growth translates into the network attributes of high performance, high bandwidth, low latency, stringent SLAs, high reliability, and high security.
- It may be necessary to supplement the key features of cloud-network convergence and the core business value for sustainable digital supremacy. Every industry has different demands and expectations for cloud-network convergence.

- The target is a digital suite of converged integrated IP and optical transport-enabled intelligent cloud network infrastructure.
- The IP and optical network are the base of the cloud network, and we can then divide into different phases. For example, the first step is to build a gigabit optical network, the second is cloud network collaboration, and the third is cloud-network convergence.
- Overall, the target of cloud-network convergence is to achieve and ensure the following:
    - One-hop simplified access to multicloud interconnections
    - End-to-end deterministic networking capabilities
    - Secure cloud edge device collaborations
    - Heterogeneous consumer and industrial IoT access
    - Intelligently connected industrial and consumer metaverse
- The whole industry ecosystem, including service providers, vendors, terminal device manufacturers, and standardization bodies, should collaborate to tap into the enduring value of cloud-network convergence.
- Terminal device manufacturers need to pay attention to the ability to use the cloud to enhance the application capabilities of terminal devices.

APPENDIX

METHODOLOGY

The WBBA used consultative discussion among members, use cases, and data gathering via the Omdia / Informa Tech platform. The exercise focused on a detailed IP and optical-enabled cloud-network convergence analysis for considering new and emerging services.

FURTHER READING

Below is a list of strongly recommended Omdia routing and switching pillar reading material, technology white papers, blogs, and thought leadership opinion pieces for more expansive topic-by-topic coverage.

Omdia commissioned research The research on the trends of Data Communication Networks for 2030 (December 2022)

Omdia commissioned research IP private line + X helps CSPs to become digital network MSPs (April 2023)

Omdia commissioned research Unleashing an Intelligent Cloud Network to Inspire New Growth (February 2022)

IPv6 Will Drive the Future of the Internet (July 2022)

Broadband ARPU Growth Strategies – 2022 (March 2023)

A Market and Technology Analysis of the 5G Transport Network Slicing Journey (August 2021)

Network Slicing in 5G (March 2020)

“The enduring value of IP routing and switching networks for Industry 4.0” (April 2023)

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