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Toward 100Tbps and a Simplified All-Optical Network

All-Optical Networks for the F5G-Advanced Era

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Contents

Summary

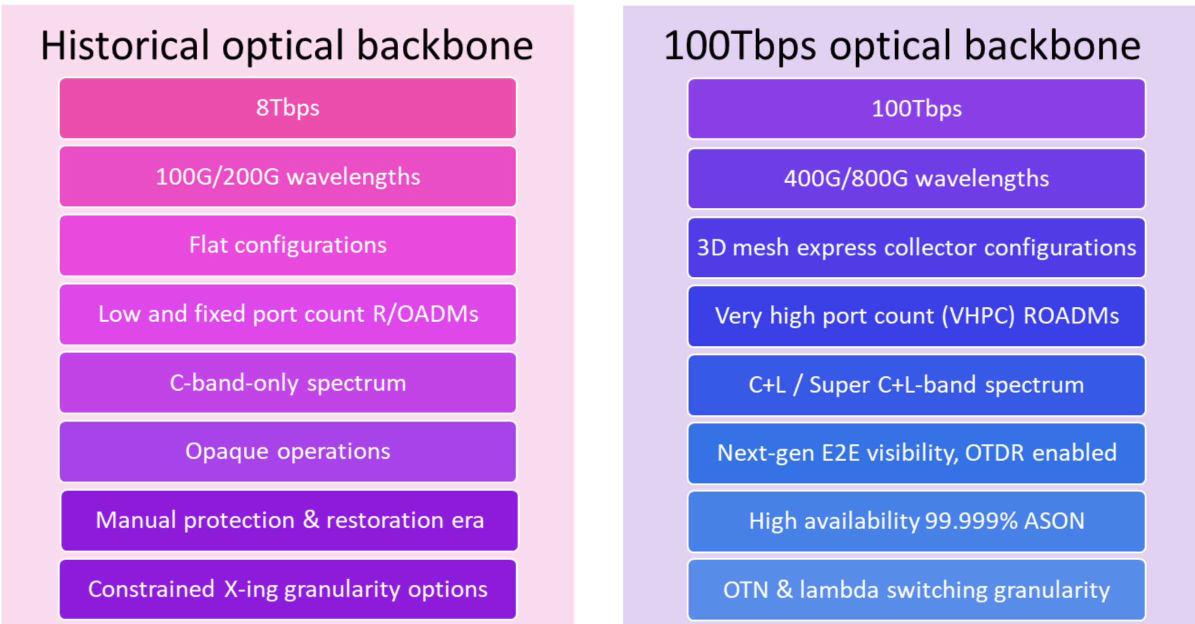
Optical network drivers

Advanced artificial intelligence (AI), cloud, video and at-home services, along with the latest high-capacity fixed and wireless access technologies, are crystalizing the need for the 100Tbps optical core. The global digital economy resides in a vast network of fit-for-purpose data centers. The global optical network is the arterial connectivity for enhanced intelligence. “The digital economy drove the last five years of optical network growth, AI will drive the next five years.” (Omdia *2024 Trends to Watch: Optical Networks*). The green 100Tbps optical core is the lifeblood of tomorrow’s communications.

Toward 100Tbps 3D-mesh backbone

Optical backbones are rapidly modernizing into the 100Tbps era. Backbones are transitioning from the historical optical backbone to the modernized 100Tbps optical backbone (see **Figure 1**).

Figure 1: Evolution of the optical backbone



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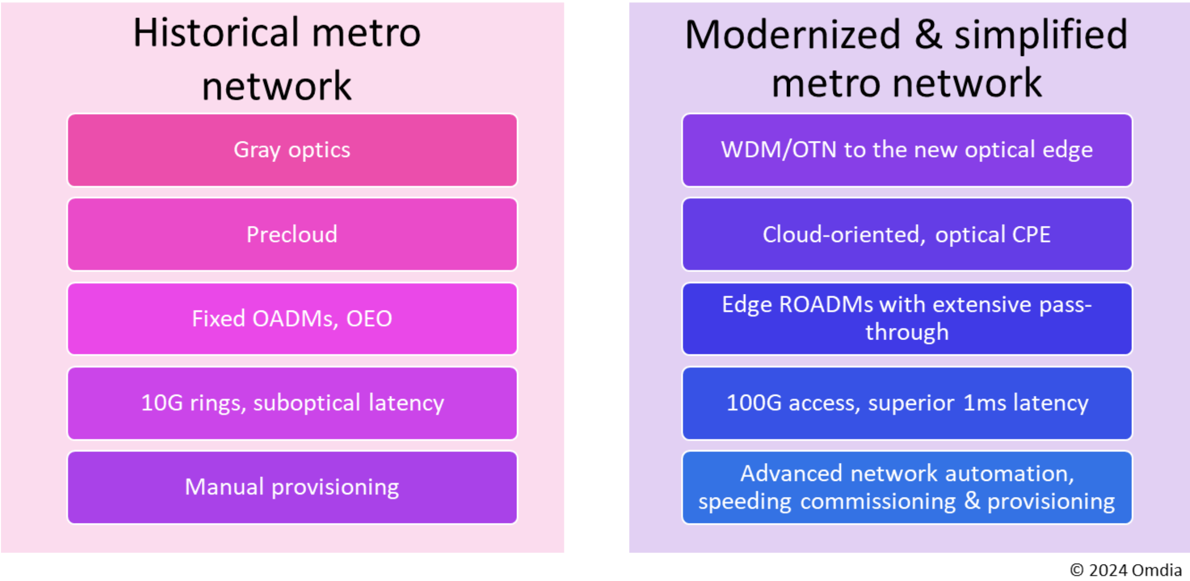
Source: Omdia

The simplified metro network

Figure 2 shows the transformation the metro network undergoes with the extension of the optical edge.

Figure 2: Evolution of the metro network



Source: Omdia

Modernizing both metro and backbone will enable carriers to deliver a high-performance experience to all of their clients while improving internal total cost of ownership.

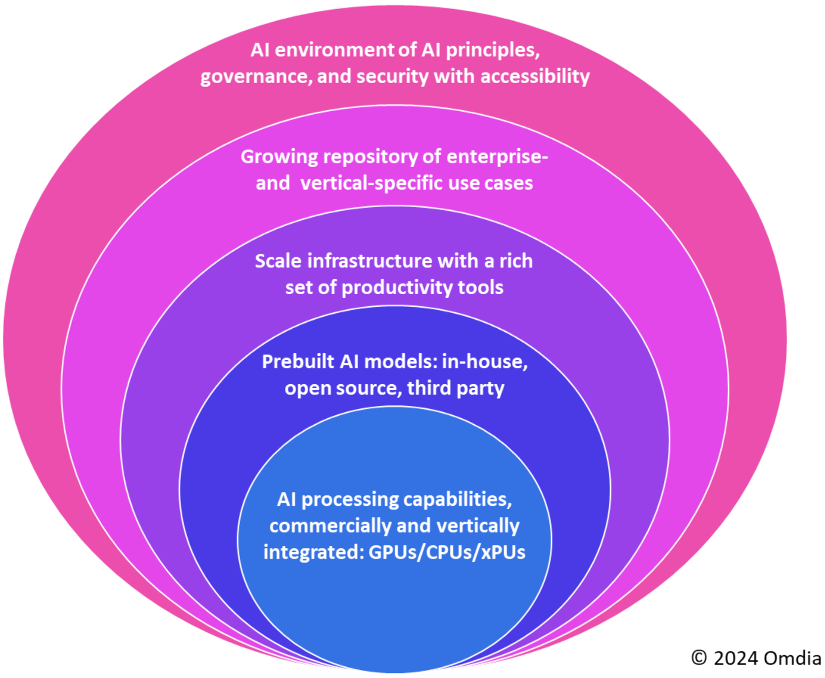
Optical network drivers

Advanced services driving growth of optical

Broadening usage of AI capabilities for enterprises

The AI application space is developing. Many enterprise verticals are taking ever more interest in AI. The AI-enabling industry is maturing. Leading AI providers have advocated their AI principles for responsible AI market development with the end goal of a mature, governed, and secure ecosystem. AI providers are focused on making AI accessible and building a scalable infrastructure with a rich set of productivity tools. The AI ecosystem will begin to drive optical network infrastructure.

Figure 3: Developing AI ecosystem for enterprise vertical applications



Source: Omdia

The connectivity community needs to be attuned to the triggers that will catalyze greater AI-driven data center interconnect (DCI) WAN growth. Potential triggers include

- The overall scale of AI

- Multicloud implementations of generative AI
- Power limitations at individual sites, necessitating distributed solutions

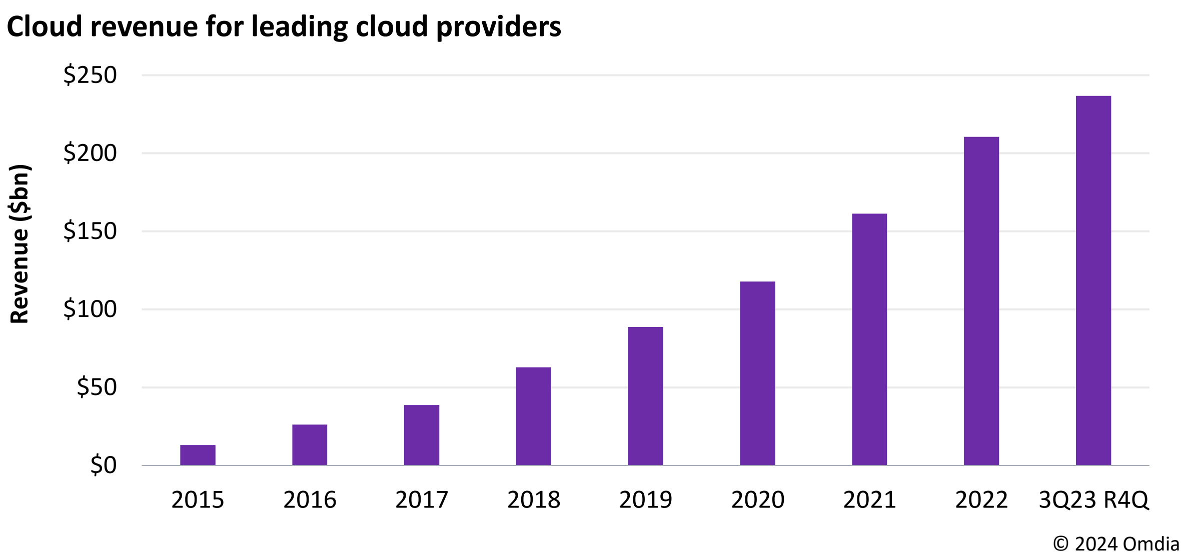
Enterprise transition to hybrid and multicloud

The transition to cloud services covers all verticals. The enterprise transition to cloud is a very real here-and-now market driver. Omdia tracks the revenue of the top cloud providers, and it is now nearing the $250bn mark, (see **Figure 4**). Perhaps more impressive than the direct revenue performance are the specific vertical applications that have shifted to the public cloud:

- Financial matching engines (the heart of stock exchanges)
- Healthcare and insurance
- Individual countries' backup of key government records

The public cloud's scale and modern infrastructure also enable more sustainable IT capability.

Figure 4: Leading cloud providers, impact on the market

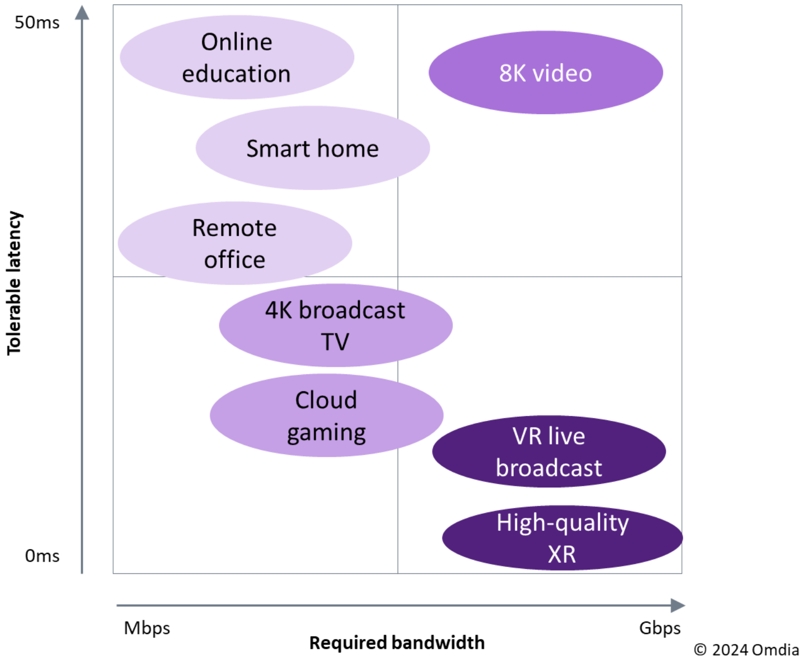


Source: Omdia

Video services: From passive high definition to interactive/immersive

Immersive video, nascent today, continues to progress. Consumers have become comfortable with earlier generations of 360° video including applications that provide a 360° view of cities, roadways, and neighborhoods. In real estate sales applications, 360° capabilities are helping to accelerate the sales cycle. In 2024, Apple Vision Pro, with 23 million pixels, is purported to revolutionize both entertainment and the work-at-home environment. Immersive video will take a little time to achieve mass-market, high-volume adoption. In the meantime, many consumers continue to shift to both 4K and 8K video.

Figure 5: Video and at-home services, bandwidth and latency requirements



Source: Omdia

At-home services for work, education, entertainment, and e-commerce

The growth of the home-based digital economy activity is well known. Working at home has become an entrenched activity. Entertainment and e-commerce at home have always been embraced by consumers. Digital economy services delivered to the home are here to stay with growth continuing. Nations around the world now view at-home services as essential utilities and continue to strive toward 100% accessibility for all households. The shift from entertainment focused to work, education, and commerce focused has led to heightened service and performance expectations.

Table 1: Modern performance and service expectations

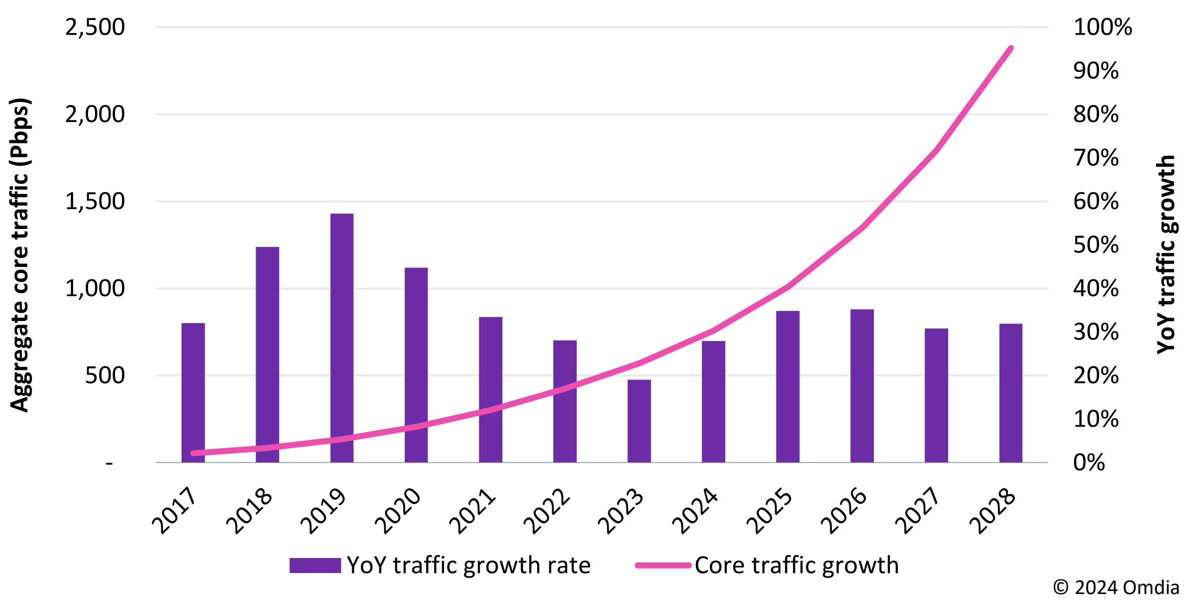
	Historical performance and service expectations	**Modern performance and service expectations**
Mobile access and services	Voice only with tolerance for lower grade of service.	High-performance bandwidth to support video and other services: zero packet loss, no service hits.
At-home access and services	Entertainment only. No business-grade expectations.	High-performance bandwidth: business quality with low latency and minimal jitter. Clients are latency aware.
Enterprise access and services	Bandwidth required between HQs, branches, and partners.	Massive IT transformation from in-house to cloud. Network becomes far more critical: high-performance capacity. Customers are latency- and jitter native.

Source: Omdia

Core network traffic growth

As the underlay and connective tissue of all services and all networks, optical networks will continue to have many drivers. Many service provider market leaders have deployed modern at-home networks, 5G RAN with the xHaul upgrade. Additionally, many of their enterprise customers have deployed advanced hybrid and multicloud IT architectures. The end customers of the advanced communications service provider (CSP) community will have deployed 4K and 8K video and will be the early adopters of the next generation of immersive video. With all of the above service and technical capabilities, core network traffic will continue to grow both as more customers are added to the networks and as all customers consume new and additional digital economy applications. And now, AI has progressed and matured to the point where it will begin to consume more compute, storage, data control network (DCN), and DCI WAN network resources.

Figure 6: Core network traffic growth



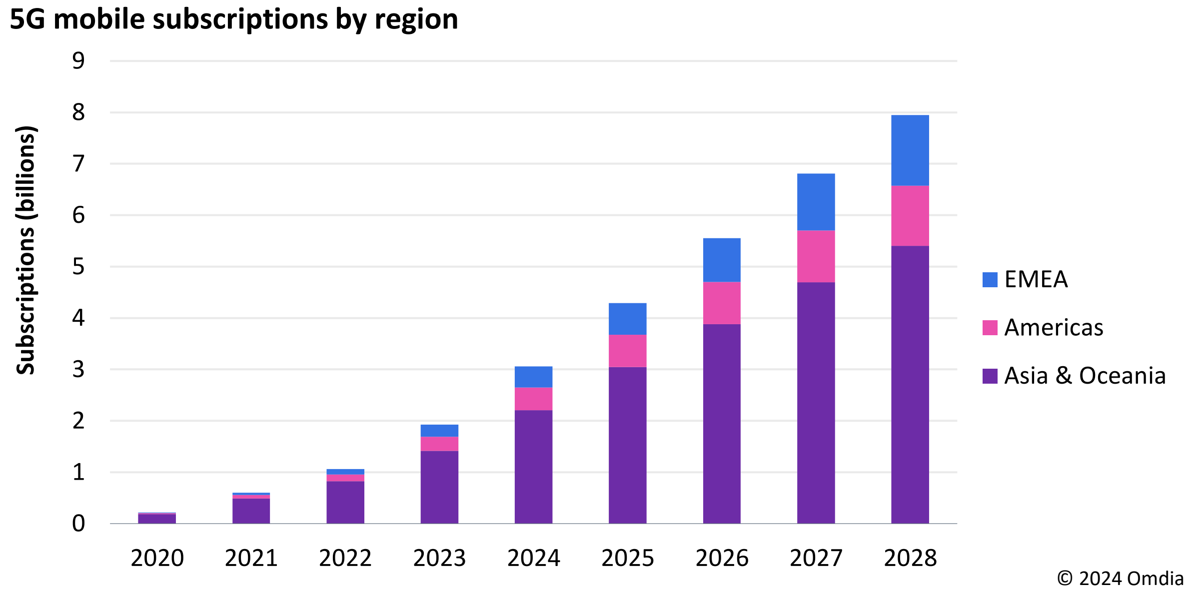
Source: Omdia

Access network trends

Mobile network upgrade from 5G RAN to 5G Advanced

Mobile networks continue to be upgraded. Many leading service providers have completed their initial upgrade of the radio access networks to 5G. The next wave of countries and CSPs are continuing their transition to 5G RAN. The leading countries and CSPs are planning to introduce 5G-Advanced capabilities based on the 3GPP Release 18 scheduled for completion in 2024.

Figure 7: 5G subscriptions progress



Source: Omdia

The new technology and network capabilities introduced by 5G Advanced will enable a new wave of futuristic applications. A small sample of the new 5G-Advanced performance capabilities includes

- Advanced downlink/uplink MIMO for improved throughput and more
- Enhanced sidelink to support new spectrum types and bands (unlicensed and mmWave)
- Time-sensitive communication to support deterministic networks for latency and packet loss improvements

The highlights listed above represent only a small selection of performance improvements. In addition to these and others, Release 18 will also feature management and efficiency improvements and enhancements for specific use cases.

Many new high-performance use cases will be supported by 5G Advanced. An abbreviated highlight set of use cases includes

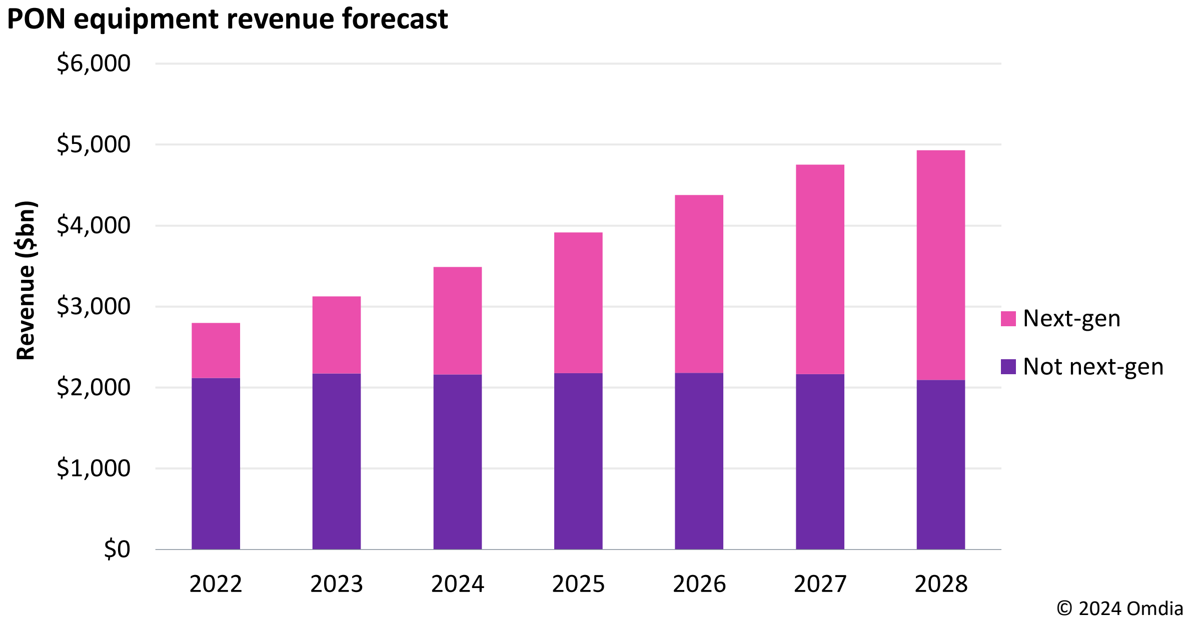
- Enabling the Industrial Internet in manufacturing by delivering sub-10ms latency
- Accelerating video uploads by increasing uplink capacity to 1Gbps
- Enhanced extended reality (XR) experiences supporting more users with higher resolution

PON upgrade path from F5G to F5G Advanced

Of late, the fixed access side has boomed. The appetite for high-performance digital economy services continues to grow, and governments have recognized high-performance connectivity as an essential utility and a table-stakes requirement for national development and competitiveness.

They have backed up their objectives with stimulus funding to accelerate high-performance and ubiquitous connectivity to all households. Today's advanced fixed access networks support 10G PON, and 50G PON will follow in due course in many markets. See **Figure 8** for Omdia's forecast on the transition from PON (up to 1Gbps) to next-generation PON (10G and beyond).

Figure 8: Transition to higher-capacity next-generation PON



Source: Omdia

IP routers upgrading from 100GE to 400GE sockets and pluggables

High-performance edge and core routers are also in the midst of a generational transition. The mainstay of router I/O for many years was 100GE ports. The router market now has rapidly transitioned to 400GE-capable I/O sockets. The router sockets can be initially populated with 100GE optical pluggables. As clients require support for higher bandwidth, the router sockets can be upgraded with 400GE optical pluggables.

Digital economy and connectivity growth

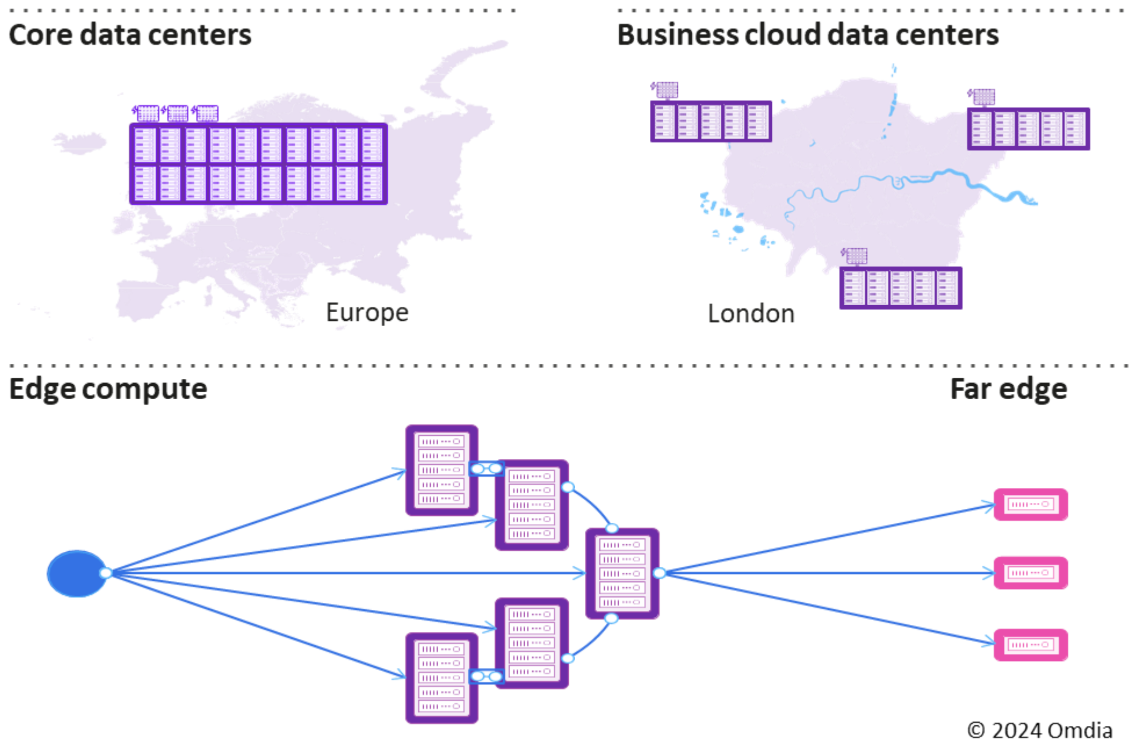
The digital economy continues to drive data center expansion

The major digital economy players continue to build a global hierarchy of data centers (DCs). Omdia has identified three major classes of DCs: core DCs, business cloud DCs, and edge compute. Core DCs are either very large data center facilities or campuses of DCs. The major providers continue to expand existing operational campuses and build new greenfield campuses in new regions of operation.

The business cloud DCs are often smaller in footprint than the core DCs but are closer to enterprise customers, enabling lower-latency performance. Edge DCs have arisen as a category, bringing smaller-scale compute closer and closer to business and consumer clients.

All DC types continue to exhibit growth worldwide. Looking ahead, the AI data center will represent a new class of DC, designed from day one to support high-power GPU-centric AI architectures.

Figure 9: The hierarchy of global data center buildouts

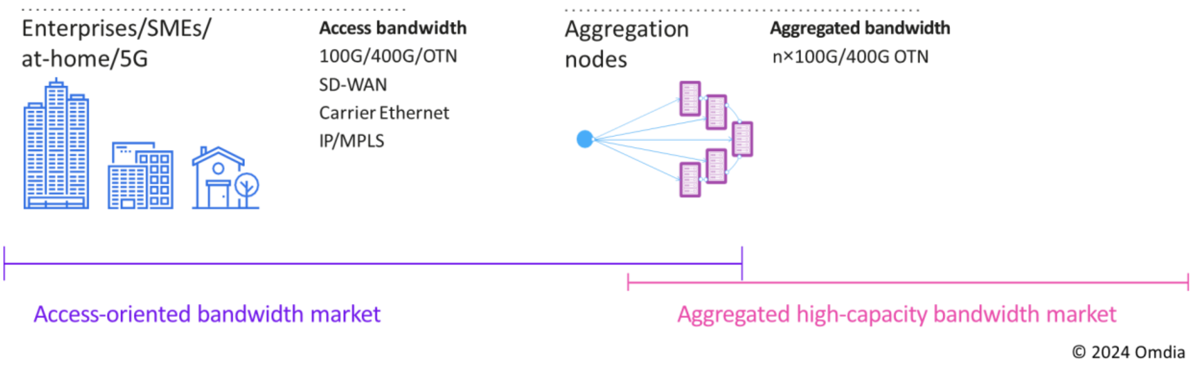


Source: Omdia

As the global data center footprint grows, the arterial optical network connectivity needs to continue to grow to keep pace. Two major types of connectivity are growing in response:

- Access middle mile from enterprises/SMEs/at-home/5G to the cloud (**Figure 10**)
- Very-high-capacity cloud core connectivity (**Figure 11**)

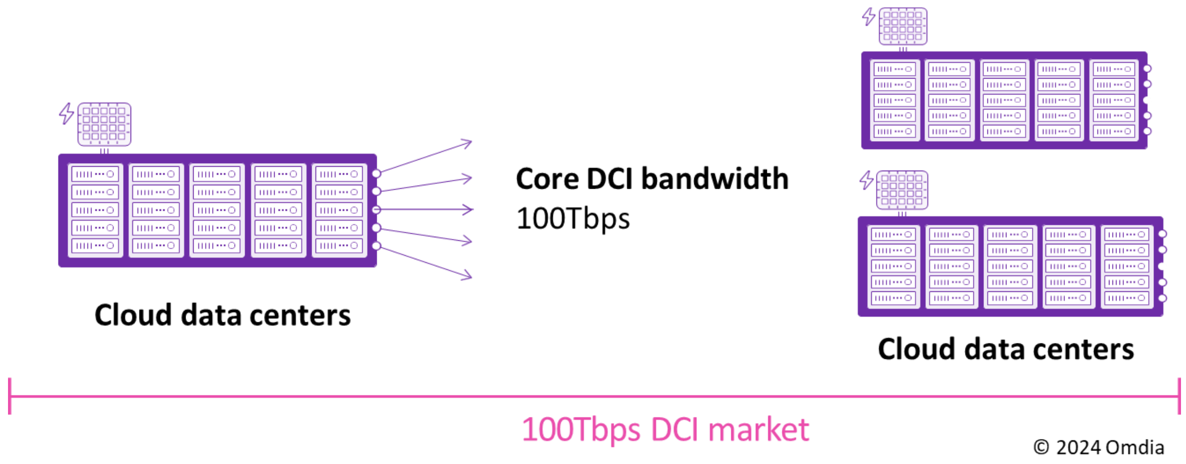
Figure 10: Modernized metro middle-mile networks



Source: Omdia

The multi-terabit DCI bandwidth connecting the large-scale DC clusters continues to grow.

Figure 11: The modernized metro DCI-centric core



Source: Omdia

CSPs and cloud service providers have in and out of territory high-capacity bandwidth requirements. When CSPs or cloud service providers (SPs) have needs beyond their fiber footprint, they explore the high-capacity wholesale market. Today, the high-capacity wholesale market centers around 100Gbps wavelengths.

The next evolution in the high-capacity wavelength market will be 400G wavelengths, to be quickly followed by 800G wavelengths as a service. Ecosystems do take time to develop, but 100G as a network currency benefited from many developments including:

- Widespread 100G-capable optical networks with intercarrier federation for 100G
- 100G-capable core routers, 100G-capable DCN (100G within major data centers)
- "Quotable infrastructure" for 100G (e.g., full back-office support)

For 400G to be utilized in the same way, the entire 400G infrastructure needs to develop so that a robust 400G-as-a-service market can come to fruition at scale. A future 800G as a service will benefit and leverage the efforts to develop 400G as a service. First, 800G will be deployed as an infrastructure, and 800G will then likely be available as a wavelength service on a limited, very custom basis. As the entire ecosystem develops, 800G will be developed as a scale service as seen with the earlier 100G wavelength market.

Data-center-oriented platform attributes

DC-oriented network equipment, often known as DCI, has a set of optimizations for the data center interconnect applications. The buying community for DCI deployed general-purpose optical network platforms many years ago but over time asked the vendor community for features, capabilities, and attributes that met their needs more directly. Features of DC-oriented platforms include

- Depth of 600mm, akin to server depth in high-performance data centers
- Front-to-rear air flow to take advantage of data centers with hot and cold aisles
- Flexible power supply including options for AC/DC/HVDC
- Very high chassis capacity of up to 3.2T/6.4T per slot capacity
- Very-high-capacity systems overall to support multi-terabit bandwidth needs
- Energy-efficient platforms that minimize power consumption per terabit of transmission

Fundamental technology advances

Optical technology is transitioning from 100–200G to 400–800G

The GBaud is the unit of measurement of the symbol rate—the speed of transmission. As each generation of optical technology is brought to market, the GBaud available steps up for better performance and faster transmission speeds. There is also a relationship with system reach. Higher-capacity transmission can support DCI requirements. Lower-capacity transmission can support ultra-long-haul distances.

Table 2 highlights the current generation of baud rates, 120GBaud, one future rate 200GBaud, and three earlier generations. Additionally, the typical transmission rates are matched to typical reach categories. The table gives a simplified view to portray a quick summary of a decade of coherent transmission progress. Many corner cases exist, and with programmable modulation formats, other speeds can be deployed.

Table 2: Baud rate generations, highlighting typical capacity-reach capabilities

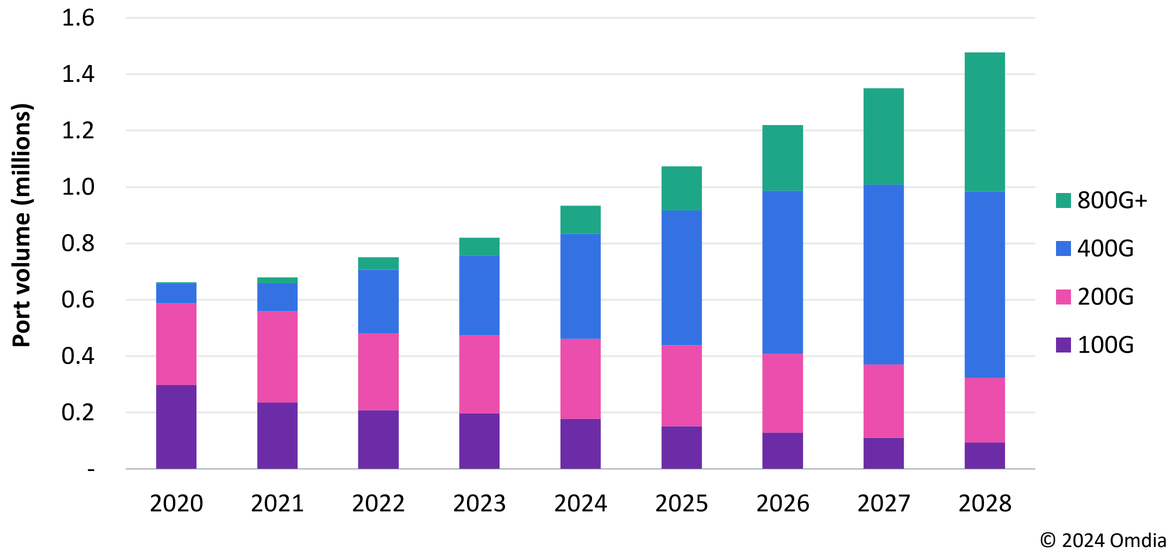
	GEN30+	GEN60+	GEN90+	GEN120+	GEN200+
Backbone	100G	100G	200G	400G/800G	800G
Metro core	100G	200G	400G	800G/1.2T	800G/1.6T

Source: Omdia

The important takeaway is that each generation of transmission technology enables a maximum capacity for a given reach category. The industry is constantly striving to maximize the capacity-reach product.

With GEN120 becoming a generally available product, GEN120 is underpinning a major shift in networks: evolving from the classic 100–200G era to a 400–800G-1.2T era. See **Figure 12** for optical port shipments by maximum capacity up to 2022 and for the forecast for 2023 and beyond.

Figure 12: Metro and backbone optical core port volumes by maximum capable speed



Source: Omdia

OTN propagating to aggregation to the edge central office

The OTN bandwidth management technology was first introduced in the network core to perform the grooming, aggregation, and switching functions. As the technology gained usage and success, it has become a technology option of choice to aggregate and groom network edge traffic. For many CSPs, the typical trigger for considering an OTN to central office upgrade occurs as their legacy Sonet/SDH networks age and come due for replacement. An OTN to the edge CO upgrade enables a bandwidth uplift and reduces OEO conversions required to transit multiple Sonet/SDH rings.

Toward 100Tbps 3D-mesh backbone

CSP priorities for backbone networks

Optical backbone routes endure for decades. CSPs require that their optical backbone cores are built to last. Long-haul amplification common equipment can be deployed in many sites that can be both remote and unstaffed. Ideally, new deployments at these sites require minimal maintenance and/or upgrade over long timeframes.

Optical backbones need to be able to rapidly scale as new network demands arise. Optical backbones need a certain amount of agility to respond to new, high-capacity, revenue-generating opportunities. Optical cores can be used for both carrier infrastructure and very-high-capacity services. In the carrier infrastructure case, revenue-generating lower-speed services are aggregated and transported across the optical core. In the high-capacity wholesale case, wavelengths can be sold directly off the optical platform. Networks that interconnect key data center assets, subsea cable landing points, and intercarrier peering points will be well placed to deliver wholesale, transit, and DCI services.

CSP priorities for the optical backbone cores are

- Low capex cost per bit from the perspective of the equipment, the site, and fiber
- Low opex cost per bit for ongoing operations and maintenance
- Support for rapid turnup to facilitate revenue-generation opportunities
- Service availability of 99.999%

100Tbps 3D backbone target architecture

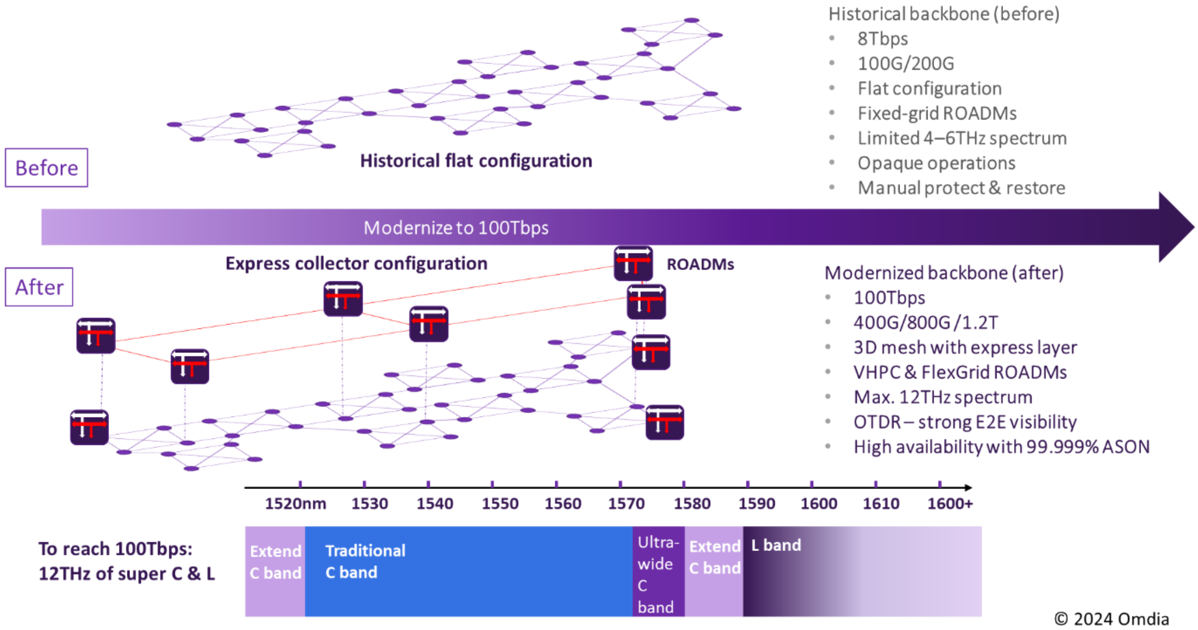
The DC-centric optical backbone target architecture of the future needs to have the following attributes:

- Optimized for growing data center to data center traffic patterns
  - Central DC to central DC
  - Regional DCs into central DC
- Flexible network architecture with VHPC ROADM wavelength management
  - Enabling colorless, directionless, contentionless, and gridless performance

  - Mesh architecture to support rapid turnup
  - An express collector architecture to optimize A–Z routes
- Scalable network architecture to deliver optimal cost per bit
  - 100Tbps: high spectral efficiency and full utilization of all practical spectrum
  - Maximum system reach for 400G wavelengths; system reach of greater than 3,000km will all but eliminate the need for regeneration
  - Support for 400G, 800G, 1.2T, and 1.6T with maximum reach per individual speed to maximize the overall system capacity-reach product, enabling the lowest total cost of ownership
- Next-generation operations and maintenance capabilities with
  - High availability with ASON (99.999%): robust diversity and rapid failover capability
  - Visible latency performance for primary and secondary paths via latency visualization tools

Large-scale networks grow at uneven rates in different sections of the overall network. For example, in major country or continental networks, the traffic between the largest sets of city pairs can grow fast, while in more remote regions with much smaller populations it grows at much slower rates. These dynamics necessitate the overbuild on selected key routes, while other routes have yet to fill. The divergent traffic pattern dynamics are best managed with a collector-express configuration.

Figure 13: Modernizing the backbone core to 100T 3D mesh with express layer



Source: Omdia

Backbone network refresh use cases

Tier 1 European network operator optical backbone network refresh

The Tier 1 CSP has deployed a fully flexible photonic mesh with nearly 100 sites of very high port count ROADM. The CSP is also testing 800G on its production network at distances of over 1600km.

The Tier 1 CSP optical backbone network objectives also include:

- Evolving wavelengths from 400G to 800G and ultimately to 1.6Tbps
- Expanding spectrum utilization from extended C band to C+L
- Enhancing reliability with hybrid ASON deployment with a restoration target of seconds
- Automation targets include auto-diagnosis and network self-healing
- Efficiency targets include cost per bit and power reductions

European competitive service provider

A competitive European service provider's historical countrywide network was 100G based with a maximum capacity of 8Tbps. Network operations were manual in nature with end-to-end visibility challenges. Network congestion impeded the capture of DCI revenue.

The new enhanced network featured 400G "3D mesh" collector-express configuration.

The key benefits were as follows:

- Expanded system capacity to 48Tbps
- Proactive pursuit of growing DCI business, enabled by 3D mesh
- Much improved network management visibility from 12 to 188 channels
- Automation of manual operations tasks

The simplified metro network

CSP priorities for metro networks

CSPs' priorities for their metro optical network include simplified networks with a superior client and operations experience and optimized cost. Historical networks are built over many years, layer upon layer, akin to a complex archeological site. CSPs want to reduce this complexity and migrate to a simplified, de-layered network. Additionally, the new network requires the following characteristics:

- Robust high availability
- High performance, low latency
- Zero packet loss to ensure an optimal client experience

CSPs also want an optimized cost profile, matching costs directly to revenue growth:

- Ability to expand network capacity on demand as opposed to overprovisioning
- Fiber utilization reduction: from multiple fibers to one fiber pair
- Removal of any unneeded OEO conversions

Modernized operations and maintenance capabilities include:

- Multilayer collaboration
- Rapid and one-click network element commissioning
- Online and automated wavelength planning, allocation, optimization, and provisioning
- eOTDR functionality

The simplified metro target architecture

Metro optical networks are undergoing a renaissance. Access technologies have taken a generational step up, which in turn requires the metro middle mile and metro core to take a step up in performance. PON is rapidly transitioning from 1G to 10G and 50G. Deployments of 5G have rapidly increased the capability and capacity of the mobile networks. Enterprises have stepped up their access connectivity.

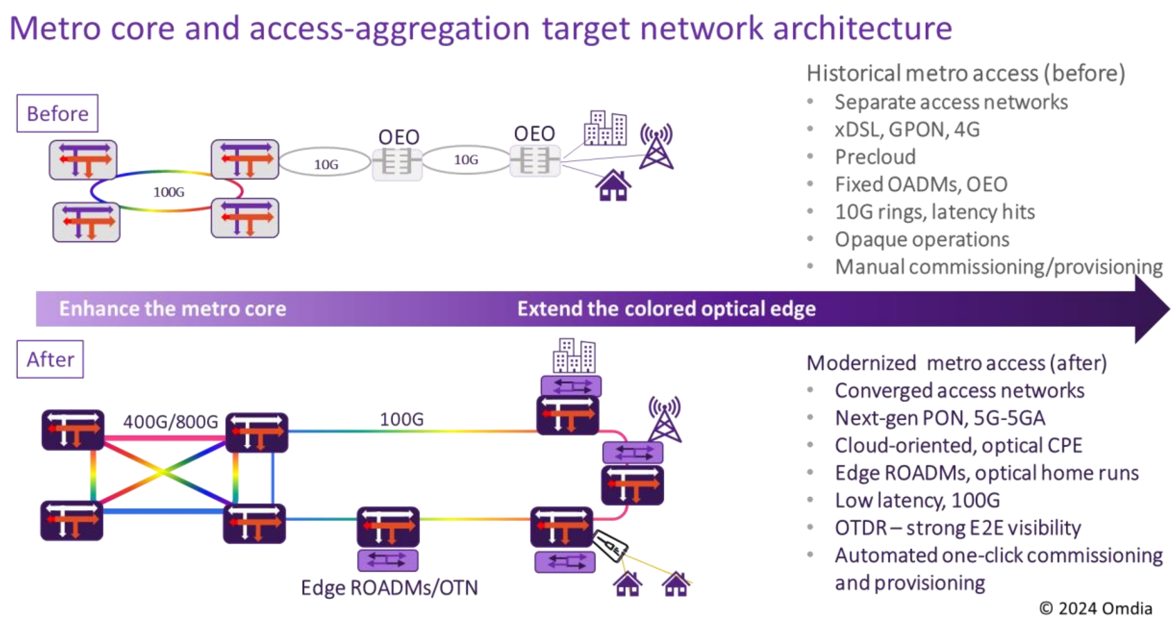
The increased bandwidth in turn creates a virtuous-circle dynamic with services and applications. As access connectivity increases, new applications become viable. Cloud services for enterprises are gaining marketwide acceptance. Video services over 5G RAN are widespread. With enhanced bandwidth to the home environment, at-home services for work, education, entertainment, and e-commerce become more widely utilized and adopted.

All of the access technology enhancements, together with greater adoption and utilization of advanced services, lead to heightened performance expectations.

The simplified metro target architecture of the future needs to have the following attributes:

- Metro core
  - Optical mesh configuration, VHPC ROADMs with FlexGrid
  - 400G/800G
- Higher capacity to the distributed central office, extending the optical edge
  - 100G/200G wavelengths to the distributed central office / first aggregation point
  - Edge-optimized ROADMs
- Simplified architecture
  - To a leaf and spine with no intermediate OEO required
  - OTN to the distributed central office / first aggregation point
- Modernized operations and maintenance
  - Edge-optimized ROADMs for flexible wavelength management
  - eOTDR for fine-grained visibility and network control
- Network automation
  - Network element autocommissioning
  - Wavelength auto-allocation and commissioning for higher efficiency to support operations and maintenance efficiency as WDM/OTN migrants to the metro access
- DCI metro networks utilizing high speeds up to 1.2Tbps

Figure 14: Modernizing the metro core and extending the optical edge



Source: Omdia

Simplified metro network refresh use case

European Tier 1 SP: Simplified and optimized network edge

The CSP's historical metro networks were separate fixed and mobile networks. Additionally, the historical network was built up in rings with substantial OEO between rings. The network lacked sufficient capacity and suffered from suboptimal latency.

The new enhanced metro network that was deployed featured the following:

- OTN to the sub central office (sub-CO). The sub-CO site housed optical line terminal (OLT) and mobile cell site gateway functionality. OTN with wavelength uplinks was deployed. The wavelengths were now "home-runned" back to the network core with no more intermediate OEO required.
- WDM was deployed and paired with OTN switching capabilities.

The key benefits were

- Immediate capacity improvement with 100G today and future option to upgrade to 200G
- Latency improvement with unneeded OEO reduction
- Improved time to market for service turnup of new optical demands
- Modernized operations with Fiber Doctor to rapidly locate and remediate fiber cuts

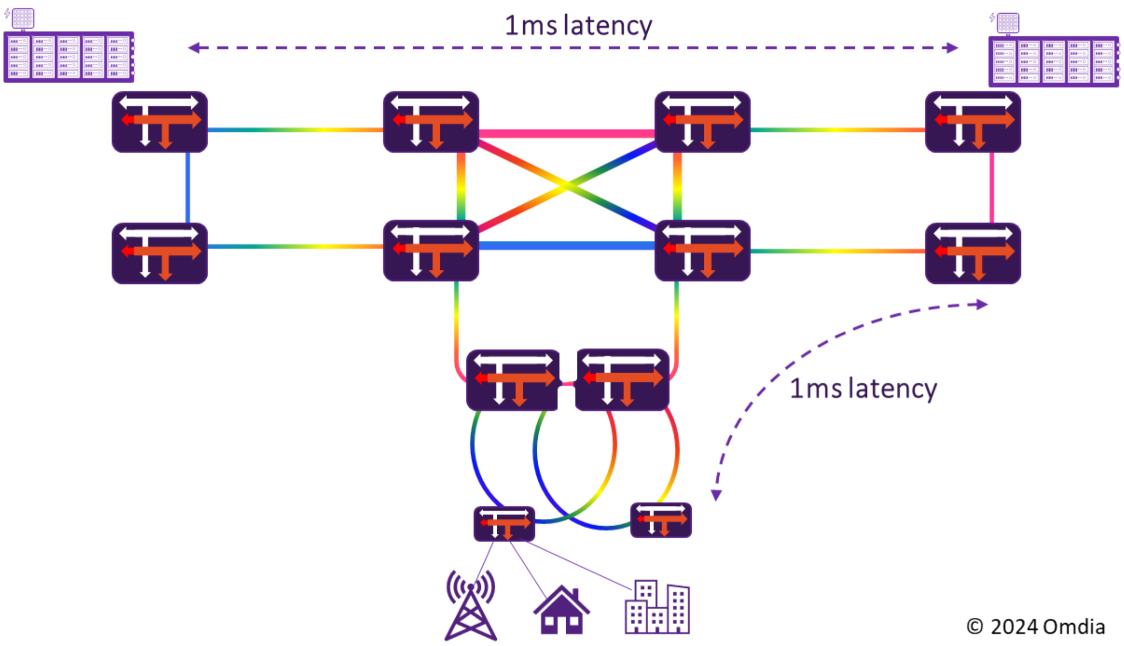
T-shape architecture

The T-shape architecture embodies both the best of the 3D-mesh backbone architecture and the modernized and simplified metro network architecture.

The key attributes of the T-shape architecture are

- Optical from network edge to core
- Enabling 1ms latency from edge to cloud
- Accomplished by optical switching throughout, no OEO en route
- Latency improvement with unneeded OEO reduction
- 100G with OTN to optical access node unifying mobile, enterprise, and PON aggregation
- Simplifying aggregation networks while upgrading access capacity to 100G
- Improved time to market for service turnup of new optical demands
- Enhanced deterministic restoration

Figure 15 : The T-shape architecture



Source: Omdia

Green networks imperative for a greener world

Networks must evolve to a greener model to support the world's transition to a greener and more sustainable environment. There are many avenues toward green. The communications industry will need to use all tools and levers available to transition to reduce the power needed per bit. CSPs can begin the journey to green via the following:

- Network architecture choices include
  - Minimize the use of nonessential electrical network equipment.
  - Maximize the use of optical network equipment: VHPC and edge ROADMs.
  - Bypass electronic switching and routing and use optical switching where possible.
  - Eliminate unnecessary OEO and maximize optical home-runs to the network edge.
  - SDH modernization to an optical to the edge with OTN will require less power per bit.

Figure 16: Renewable-energy-enabled blue skies

Source: Creative Commons

- The upgrade of the network to modern equipment is underway:
  - Each successive new generation of equipment uses less power per bit.
  - CSPs are reporting cases of upgrading network equipment solely to reduce power consumption, replacing equipment before the equipment has reached end of life (EOL).
  - Equipment can be highly optimized for individual application and therefore utilize less power.
  - Select equipment with strong “sleep mode” capabilities.
- Power source selection: the industry is transitioning to sustainable sources that do not burn carbon:
  - Not that long ago, this option was dismissed as completely impractical.
  - Many cloud SPs are directly measuring their complete power footprint and have set goals to move to completely sustainable ecosystems.
  - Cloud SPs have built scale solar and wind farm sources. Cloud SPs have located data center assets close to hydroelectric sources.

Conclusions

Optical network drivers continue

Optical networks support 5G RAN networks, high-capacity PON, enterprise cloud, and next-generation video services. AI will be the next catalyst to continue to stress the optical core.

Toward 100Tbps 3D-mesh backbone

The digital economy resides in a vast global hierarchy of data centers. Digital economy and data center expansion continues. The optical backbone is the critical arterial connectivity of this vast economy and must continue to modernize to keep pace. CSPs do have the opportunity to deploy

- 100Tbps networks based on 400G and 800G wavelengths
- The full 12THz of optical spectrum to realize 100Tbps
- Wavelength management with very-high-capacity lambda switching in the core and cost-effective lambda switching at the optical edge
- Innovative 3D-mesh architectures to match network with A–Z demands

The leading CSPs worldwide are moving to modernize their networks to place themselves on a superior cost and operations footing.

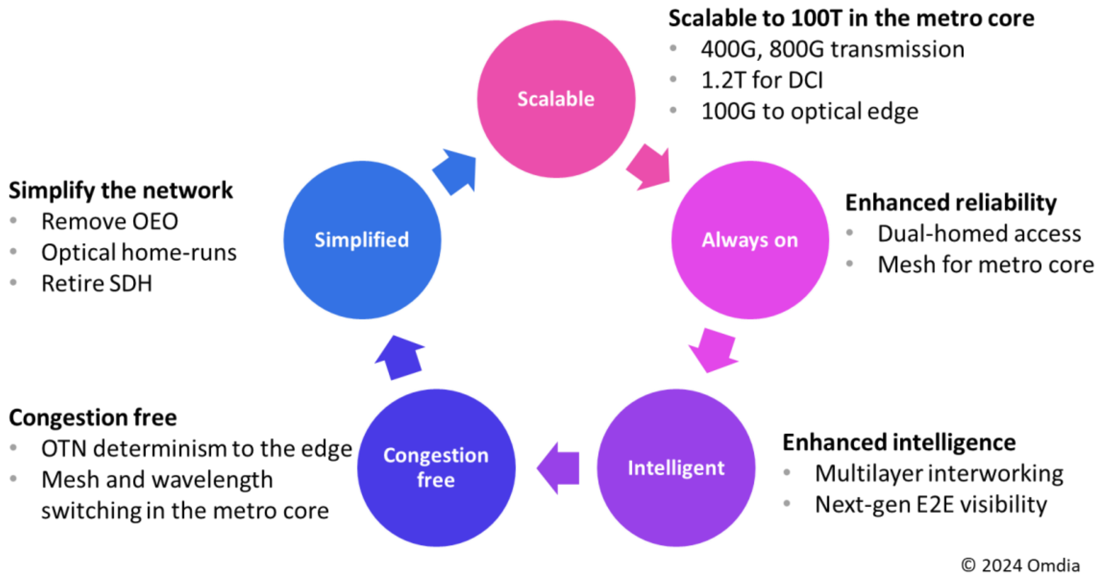
Simplified metro target architecture

The metro network continues to modernize. Networking demands at the network edge have risen fast to support 5G RAN, next-generation PON, high-capacity enterprise-to-cloud access, and advanced video. Impressive metro innovations are bringing both high capacity and elegant agility to the optical edge:

- The new hardware enablers are cost-effective and edge-optimized ROADMs and OTN XCs
- Bringing 100G WDM to the optical edge
- Paired with the security, reliability, and determinism inherent with OTN
- A multiservice edge, which modernized metro optical networks can deliver with aplomb

The leading CSPs worldwide are rapidly modernizing their metro edge networks for agility, flexibility, and cost-efficiency.

Figure 17: Attributes of the modernized backbone and metro networks



Source: Omdia

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We create business advantage for our customers by providing actionable insight to support business planning, product development, and go-to-market initiatives.

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