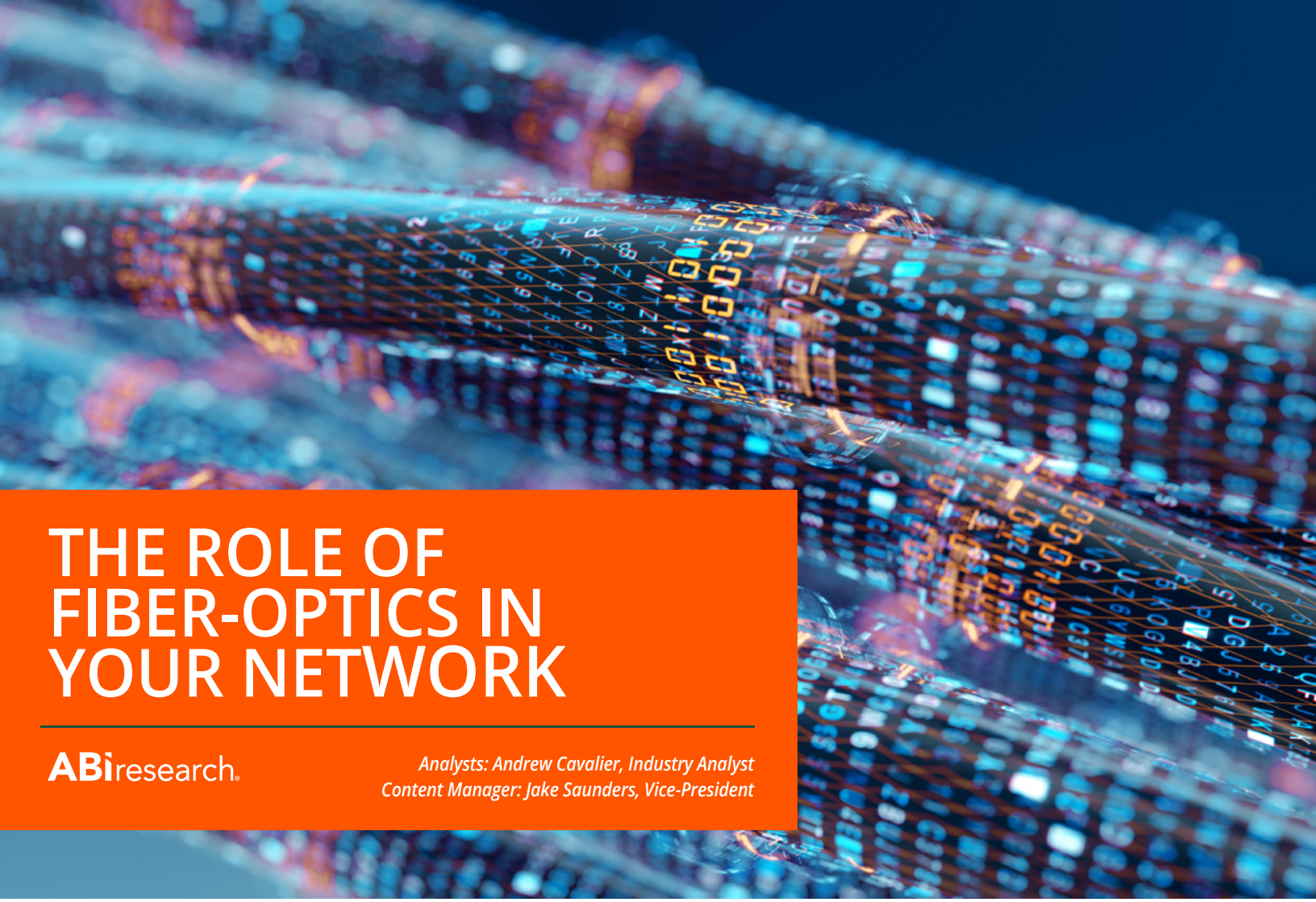

THE ROLE OF FIBER-OPTICS IN YOUR NETWORK

ABIresearch

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EXECUTIVE SUMMARY

Fiber-optics, the apex of data transmission technologies when it comes to speed, are needed now, more than ever, to support the deployment of 5G and the increasing networking needs of consumers, enterprises, and telecommunications providers (telcos). Using optical fiber cable to transfer information, fiber-optics can enable Terabits per Second (Tbps) throughput and easily support modern homes, public exchanges, and even 5G cell sites, which require Megabits per Second (Mbps) and Gigabits per Second (Gbps), respectively. New network-intensive applications, such as Extended Reality (XR), the metaverse, Ultra-High Definition (UHD) video streaming, and cloud and edge computing, have driven up data rates in homes and central offices to reach the Gbps dimension. As a result of the increased consumption of high-bandwidth content and applications, demand for high-speed broadband via Fiber-to-the-X (FTTX) continues to increase, with adoption occurring in various developed and developing markets.

Residential Homes: Network traffic to the home has seen a spike in recent years, growing to more than 512 Gigabytes (GB) per month for the average American household in 2021, up from 270 GB per month in 2018. The significant growth in both bandwidth and network speed requirements is largely tied to an increase in network-connected devices and concurrent users on the home network. Digital applications on the home network have also grown increasingly complex and network-intensive, integrating Video-on-Demand (VOD) and worldwide real-time connectivity via social media, gaming, XR, and the Internet of Things (IoT). While other connectivity solutions (Fixed Wireless Access (FWA), satellite, and mobile) exist, they complement and are often enabled by Fiber-to-the-Premises (FTTP).

Business & Enterprise: This growth in demand for network bandwidth and throughput also extends to the enterprise. Core operations at modern commercial offices are increasingly dependent on virtualized assets and collaborative tools that require users to stay always connected to the network. Enterprises not only require these resources to be always available, but have stringent performance requirements to deliver guaranteed levels of service. Leveraging the cloud and virtualized environments, such as enterprise metaverse applications and video conferencing, have become common platforms driving network resource utilization quickly into the Gbps dimension.

Alongside this, Information Technology (IT) network sophistication has grown increasingly complex, as enterprises process, store, and analyze more data and workloads on-premises. Fiber-to-the-Commercial Office (FTTCO), therefore, has become essential for modern enterprises' current and future networking requirements.

Essential Telco Infrastructure: For the telco network, fiber-optics make up the backbone of modern networks that transport data and connect the network, from the core network down to the end user. With the evolution toward 5G wireless networks, telcos now require fiber-optic infrastructure more than ever to unlock the performance of 5G Millimeter Wave (mmWave) and future 6G intelligent networks. To this end, innovations in fiber-optic technologies are a critical driving force for the transformation of networking capabilities, from the network operator down to the end user at the home and commercial office.

WHAT IS DRIVING YOUR NETWORK TRAFFIC?

Fiber-optics are at the pinnacle of data transmission technologies. Using a flexible, transparent optical fiber made from silica, these fiber-optic cables use photons to transfer information at around 2/3 the speed of light. This has positioned fiber-optics as the mainstay wired backhaul solution for Mobile Network Operators (MNOs), and the fastest and most robust networking solution for consumers and enterprises. Fiber-optic deployments are growing at around 15% to 25% per year, in large part due to their ability to support the infrastructure of new high-throughput and low-latency communications technologies, such as 5G and 5G-Advanced, and applications, such as XR, real-time UHD video, the metaverse, and digital twins. Furthermore, the global increase in data consumption at home and in the workplace is driving network operators to adopt fiber at a rapid pace to support the growing demand and performance expectations of consumers, businesses, and the telco network itself.

As a result of the consistent increase in global demand, fiber supply is experiencing a worldwide shortage, which has driven up product pricing and lengthened lead times on supply. In this respect, fiber-optic networks are required now, more than ever, to support the evolution and transformation of communication networks in developed and developing economies. Compounded by this is the challenge of supporting the evolving network usage habits of broadband users, which is driving fiber deployments closer to the end user in the home, the office, and even the room. Fiber-optics is a critical and necessary component for unlocking the digital transformation of telecommunications and user applications and experiences.

IN THE HOME

Network traffic to the home has seen a surge in usage, with the average monthly home Internet bandwidth consumed by North Americans surpassing 512 Gigabytes (GB) per household and worldwide global Internet traffic estimated to have reached 7.7 Exabytes (EB) per day in 2021. Alongside this, the global average time spent on the Internet for users aged 16 to 64 reached almost 7 hours per day in 2021.

Fixed broadband (fiber) subscriptions are forecast to increase from 660 million subscribers in 2021 to 832 million subscribers in 2028, accounting for a Compounded Annual Growth Rate (CAGR) of 3%. The increase in users, alongside the proliferation of UHD-enabled home and personal devices (~25 per household), UHD video streaming, and low-latency real-time applications (IoT, gaming, cloud, and metaverse applications), have resulted in an application bandwidth growth rate of about 40% per year.

Alongside the expansion of applications, the advent of COVID-19 and the shift to remote work have been an accelerant for the increase in network traffic and demand for better latency and bandwidth. With a growing number of applications and devices used in the home, network traffic per capita is expected to reach 49.8 GB per month by 2023. As a result of the increased consumption of high-bandwidth content and applications, the demand for high-speed broadband via FTTX continues to increase and be adopted in various markets—both developed and developing.

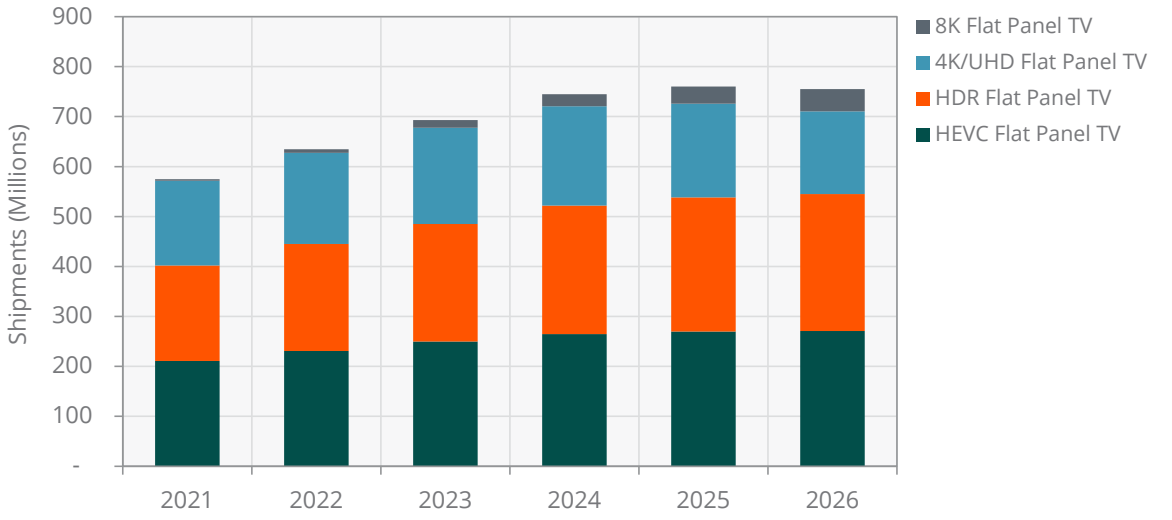
MULTIPLE TVS, 4K, & ABOVE

Television (TV) and video content is one of the key drivers for Internet traffic to the home, with 4K and UHD VOD content acting as the primary catalyst for growth. In the context of global Internet traffic, video content (streaming and downloads) is estimated to account for 82% of total Internet traffic around the world by 2023. Multi-device ownership is another key factor impacting traffic patterns, with Internet-enabled High-Definition (HD) TVs and video devices having a multiplier effect on traffic. In this respect, the bit rate needed to support 4K and UHD content, 15 to 18 Mbps is substantially higher than HD content at 5 Mbps to 7.2 Mbps and Standard-Definition (SD) content at 1 Mbps to 2 Mbps, generating far more Internet traffic on average per household. With multiple connected video devices per household streaming and downloading UHD content, network resources can become strained and the competition for bandwidth can negatively impact performance and connectivity (i.e., delayed load times, buffering, latency, and network disconnect). To this end, one of the main advantages of fiber-optics is its high bandwidth capability (typically up to 10 Gbps) that can transmit data up to approximately 100 Kilometers (km) without being optically boosted.

ABI Research estimates in its *Media Devices: Ultra HD, 4K, HDR, 8K, HEVC* market data (MD-CHD-175) that the UHD media devices (HEVC, 4K, 8K, and HDR TV sets) market will grow from 574 million shipments in 2021 to 755 million shipments in 2026, reflecting a CAGR of 5.6% during the period. Critically, 8K flat panel TVs are anticipated to have the highest growth during the period, at 68.7%, and will grow from 3.2 million shipments in 2021 to 44.5 million shipments in 2026. Based on these shipments and given that the average time watching content on residential TVs in 2021 is around 3 hours per day and UHD content streaming uses 3 GB to 8 GB per hour (252 GB to 672 GB per month), global UHD content streaming is estimated to increase from around 144 EB to 385 EB per month in 2021 to around 190 EB to 507 EB per month in 2026. This reflects a minimum of 50% of monthly network traffic to the home attributed to UHD video and VOD services.

Chart 1: UHD & Above TV Shipments World Markets: 2021 to 2026

(Source: ABI Research)



PERSONAL ENTERTAINMENT DEVICES

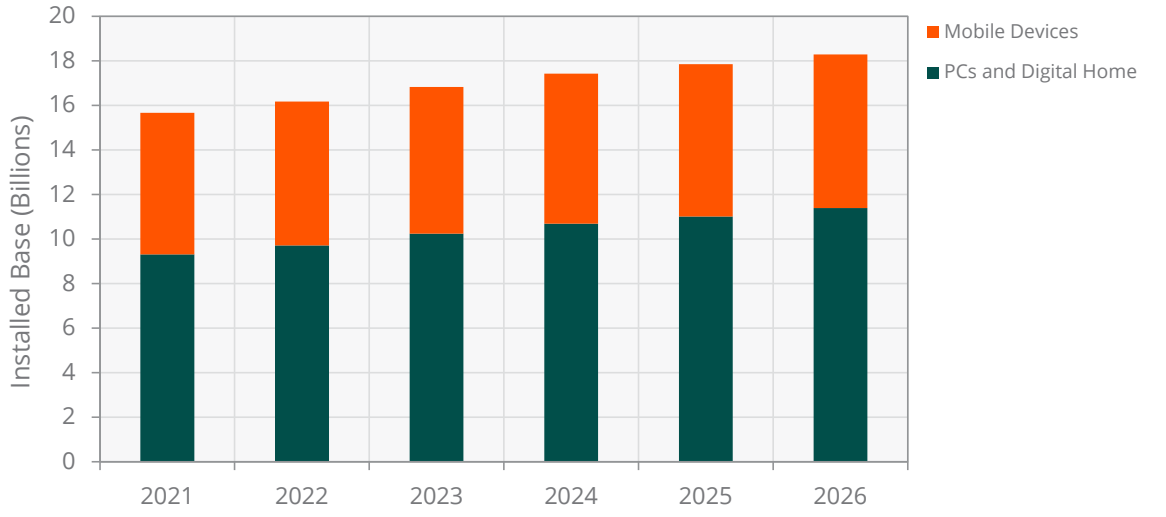
Internet-enabled mobile devices, such as tablets, laptops, and smartphones, are quickly growing as a preferred network resource content consumption method. In this respect, Comcast estimates that nearly 1/3 of all connected devices to its routers, in the home, are smartphones. The increasing interconnectedness of these devices via hardware ecosystems (Apple, Samsung, LG, Sony, etc.) has also helped drive the use of these devices in the home for various applications. In this respect, the integration of smart appliances and home management systems (sensors, noise monitoring, thermostats, cameras, lighting, etc.), which can be remotely managed with tablets, laptops, and mobile devices, has increased network connectivity requirements. Furthermore, the applications and services being accessed through these devices (live streaming and UHD content, XR and metaverse applications, gaming, real-time sensing and telematics, data analysis, Global Positioning System (GPS), etc.) are accelerating the demand for higher network bandwidth and expectations of reduced network latency.

While personal entertainment devices can be used for a host of activities like online gaming, web browsing, social media, audio streaming, and emailing, the time required to consume 1 GB of data has a relatively high threshold of 5 hours (with applications ranging from 40 MB to 200 MB per hour). Data consumption increases substantially when UHD video content and streaming are introduced to these devices, with data usage ranging from 1 GB to 8 GB per hour. In this respect, digital video (desktops, laptops, tablets, mobile phones, etc.) in 2021 reached an estimated average usage of 2 hours and 30 minutes per day per user.

ABI Research estimates in its *Internet of Everything Market Tracker* market data (MD-IOE-111) that the installed base of Personal Computers (PCs) and digital home devices (consumer electronics: TVs, gaming consoles, set-top boxes, remote controls, Wi-Fi Access Points (APs), speakers, etc.) will grow from 9.3 billion connections in 2021 to 11.3 billion connections by 2026. This segment will maintain its lead over mobile device connections during the period, which will grow from 6.3 billion connections to 6.9 billion connections.

Chart 2: Installed Base of Connected Devices World Markets: 2021 to 2026

(Source: ABI Research)



XR & METAVERSE APPLICATIONS

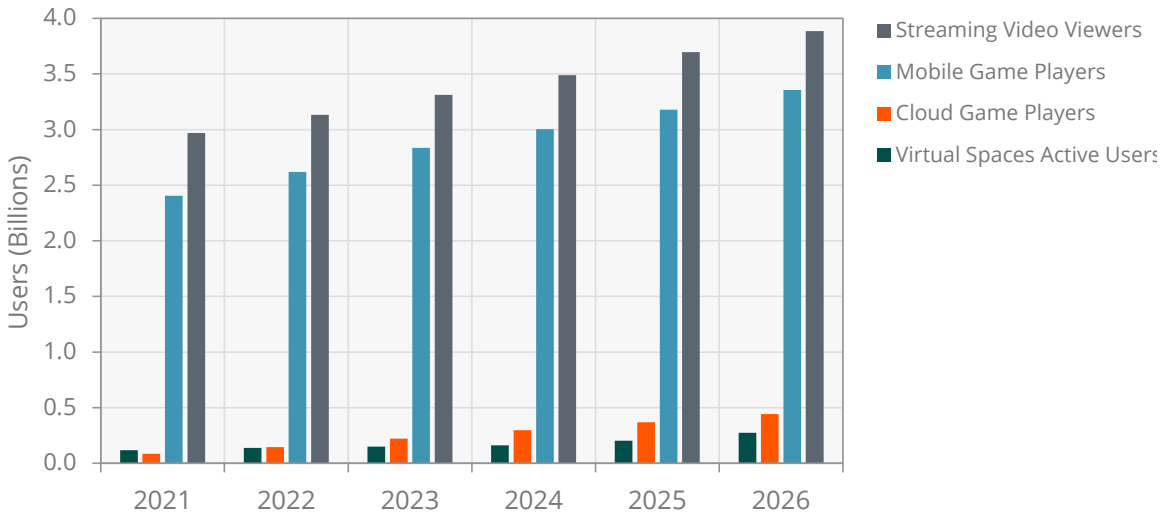
There were approximately 4.5 billion active social media users and 2.9 billion video game players in 2021. The increase in social media and video game streaming, alongside interactive video platforms has been a key enabler for metaverse applications and increased network resource consumption. Over time, consumer XR and metaverse applications, such as livestreaming and interactive audio and video, online and cloud gaming, social networking, and virtual environments, are drivers of network traffic to the home. For example, TikTok users can consume more than 840 MB of data within 1 hour of use on default settings, while YouTube livestreaming users can use up to 3 GB or more per hour depending on the settings.

While the metaverse is still struggling to bring down hardware costs and develop end-user software User Interfaces (UIs), several companies are jostling for position. Notable players include Amazon's Twitch, Google's YouTube, Meta's Facebook, ByteDance's TikTok, and Tencent's Huya and DouYu. Immersive applications with Augmented Reality (AR) and Virtual Reality (VR), live 360° video, and volumetric display are also growing in popularity and generally require greater network throughput (25 Mbps or more) and lower latency (sub-50 Milliseconds (ms)).

ABI Research's *Consumer Metaverse: Digital Content, Services, and Advertising* market data (MD-NGCS-102) reports that worldwide consumer metaverse applications will continue to trend upward, led by gaming and video streaming services. For gaming, cloud gaming and mobile gaming players are expected to increase from 85.2 million and 2.4 billion, respectively, in 2021, to 442 million and 3.3 billion in 2022. Furthermore, ABI Research anticipates that the number of streaming video viewers will increase from 2.9 billion in 2021 to 3.8 billion in 2026. Lastly, the virtual spaces segment is expected to grow from 118 million users in 2021 to 273 million users in 2026. Online gaming consumes a relatively small amount of data per hour (at 20 MB to 500 MB) compared to video live streaming, with an estimated 548 billion hours of content streamed on mobile devices in 2021, equating to 548 EB to 1.6 Zettabytes (ZB) of data. Given ABI Research's estimation of 2.96 billion video streaming users in 2021, that equates to around 15.4 GB per user per month or 75 GB per household per month (~14% of monthly home traffic use).

Chart 3: Metaverse Application Users World Markets: 2021 to 2026

(Source: ABI Research)



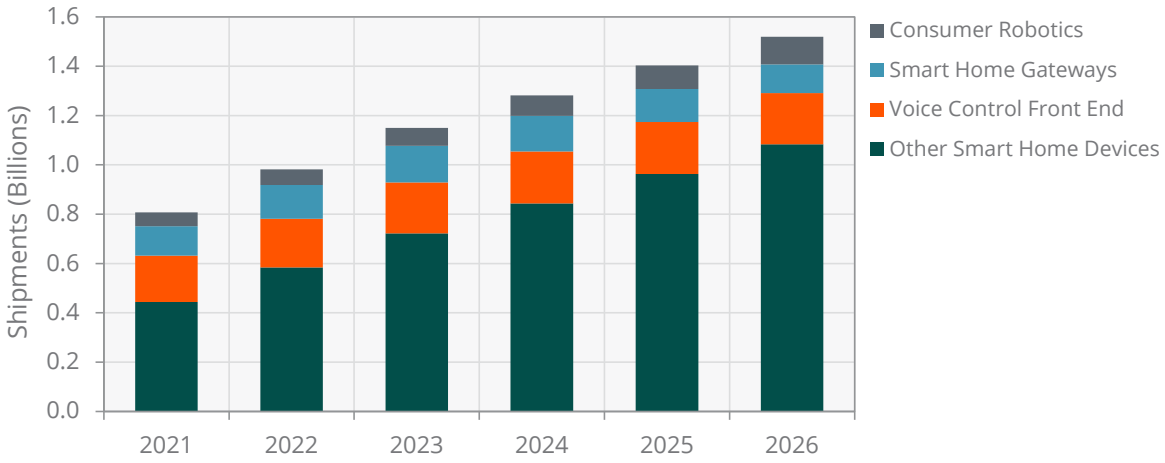
IOT & SMART HOME

The integration of smart home devices and consumer home robotics, which can be remotely managed with external devices, such as tablets, laptops, and mobile devices, has increased network connectivity requirements. Despite wireless protocol complexity impacting overall consumer adoption of smart home hardware, the use of these devices from the gateway to control devices is increasing, primarily driven by the adoption of voice control front end devices (e.g., the Amazon Echo & Alexa, Google Home, Apple HomePod, and Alibaba AliGenie lines). With smart home devices typically numbering 10 or more devices, Wi-Fi-connected cameras, and voice control front end devices that can connect to the cloud and stream online content like music or podcasts can rack up data usage. Common devices, such as doorbells, household appliances, plugs, and lights, will typically clock in at under 1 GB per month. Other items, such as smart cameras, can consume between 18 GB and 400 GB of data per month depending on the settings and features that are enabled.

ABI Research estimates in its *Consumer Robotics and Smart Appliances* market data (MD-HACRSA-103) that the consumer robotics and smart home market will experience growth in the coming years, with shipments growing from 807 million in 2021 to 1.5 billion in 2026, reflecting a combined CAGR of 13%. For voice control front end and other smart home devices, shipments are expected to increase from 187 million and 444 million, respectively, in 2021 to 207 million and 1 billion in 2026. Alongside this, consumer robotics are expected to experience high growth from 56 million shipments in 2021 to 111 million shipments in 2026, representing a CAGR of 15%. Finally, smart home gateway shipments are expected to decrease from 119 million shipments in 2021 to 116 million shipments in 2026.

Chart 4: Consumer Robotics and Smart Home Hardware Shipments World Markets: 2021 to 2026

(Source: ABI Research)



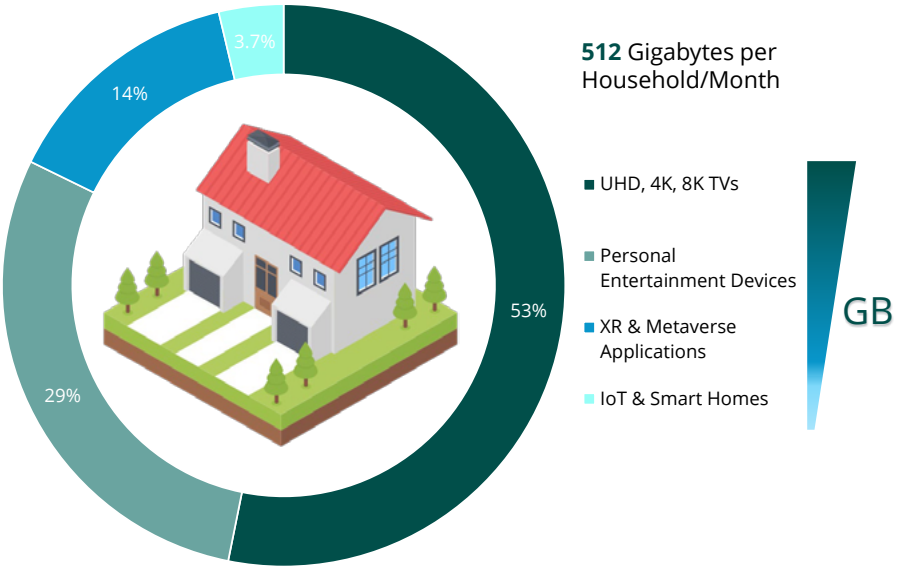
HOME TRAFFIC PROFILE

Based on the analysis of Internet data usage for different devices found in the typical home, the traffic profile for a modern home is broken down into UHD, 4K, and 8K devices and content, personal entertainment devices, XR and metaverse applications, and IoT and smart home devices. The largest category, UHD-enabled TVs, devices, and content, uses 50% (252 GB to 672

GB) or more of total monthly network traffic and accounts for 43% (or 3 hours) of total Internet usage per user per day. The next largest category, which consists of smartphones, tablets, and computers, contributes to around 29% (132 GB to 147 GB) of total monthly Internet traffic. XR and metaverse applications, which consist of social media platforms, live streaming, and video gaming, contribute around 14% (75 GB) of total Internet usage per month. Finally, IoT and smart home devices, on average, contribute between 3% and 4% (19.5 GB) of total home Internet usage. While these percentages provide a snapshot of modern home Internet consumption, this does not include the resource distribution for the homes of heavy-duty users who can potentially consume up to 1 TB or more per month, as well as larger households, which are seeing a gradual increase.

Figure 1: Home Traffic Profile—Estimated Data Usage per Month

(Source: ABI Research)



SUMMARY CONCLUSIONS

Network traffic resource use in the home is being driven by a proliferation of devices, as well as their usage habits that are incorporating an increasing proportion of UHD video content. The increasing use of personal entertainment devices, especially smartphones, and video streaming and social platforms, such as Netflix, YouTube, and TikTok, is pushing network traffic usage further into the video domain. The adoption of video content throughout the home, from IoT devices like smart cameras streaming home data, to mobile phones streaming online video games, or social media shorts, or the living room flat panel TV streaming a new binge-worthy show from HBO, are all contributing to the increasing demand for greater network bandwidth and low latency access within the home.

In many respects, fiber-optics, as broadband communications "accelerators," enable a diverse range of online applications and services in the home. There is an opportunity cost if end users experience Internet streaming lag, interruptions, or jitter. Internet access interruptions often galvanize end users into disconnecting outright. As a result, end users may be precluded from not just watching their favorite TV boxsets, but also from taking up online education classes, exploring arts and craft tutorials, downloading eBooks from their local library, or learning and testing online coding/programming.

IN THE WORKPLACE

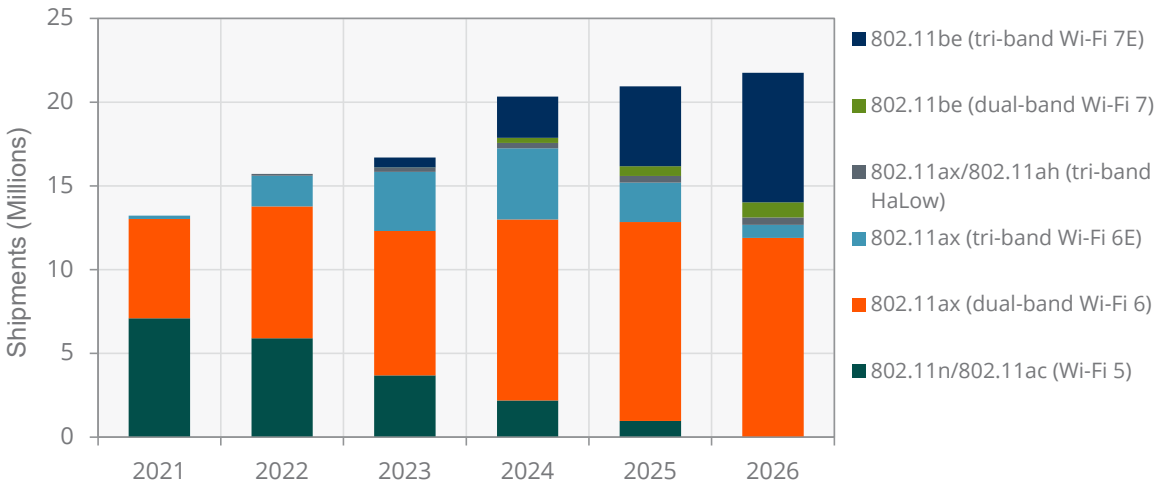
IT NETWORKS

Network traffic to the office has many potential components depending on the industry and commonly includes network routers, APs, controllers, PCs, servers, and enterprise IoT devices. With a mix of front end and back end devices using network resources, bandwidth requirements can quickly increase as network users expand from small (fewer than 10 employees) to large (1,000s of employees). Some office environments can have stringent latency and throughput requirements that enable back-office functions, such as data analytics, Artificial Intelligence (AI)/Machine Learning (ML), software development, immersive design, and manufacturing. An office with ~10 employees who may be accessing the cloud, file-sharing, and web-based services requires at least 50 Mbps. Network resource use is also tied to the activities being performed over the network, with power users like data analysts or software engineers requiring between 2 GB and 5 GB per day, while other activities like video streaming and calling may need between 1.6 GB and 2.5 GB per day.

For office IT network infrastructure, Wi-Fi is critical for connecting users and devices wirelessly to the office's router and Optical Network Terminal (ONT). Wi-Fi is evolving to support both high-throughput and low-latency applications, such as smartphones, smart TVs, PCs, and IoT devices, while also reducing power consumption and improving performance. Wi-Fi 6's key features and enhancements promise to improve in some of these areas with a 4X increase in average throughput per user, a 67% reduction in power consumption for client devices, a 35% increase in peak data rates, and reduced latency. ABI Research forecasts in its *Wi-Fi Customer Premise Equipment (SOHO/Consumer and Enterprise Market)* market data (MD-WLEQ-164) that enterprise networks leveraging standard power APs will grow in demand from 13.23 million shipments in 2021 to 21.76 million shipments in 2026, reflecting a CAGR of 10%. Wi-Fi 6E will begin to taper off as enterprises prepare for Wi-Fi 7, culminating in heightened demand for both Wi-Fi 6 dual-band APs, which will grow from 5.94 million shipments in 2021 to 11.89 million in 2026, and eventually Wi-Fi 7 tri-band APs.

Chart 5: Enterprise Access Point Shipments by Protocol World Markets: 2021 to 2026

(Source: ABI Research)



IMMERSIVE COLLABORATION SOFTWARE & SERVICES

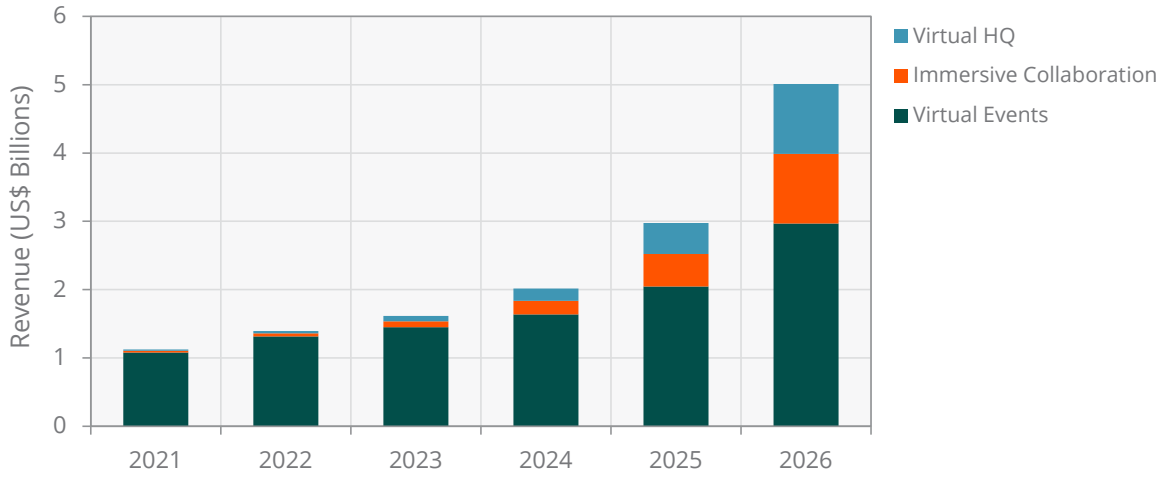
Enterprise metaverse software and services encompass a variety of interactive services and software for immersive collaboration, digital twins, and simulations. Immersive collaboration software services include virtual Headquarters (HQ) and "virtual spaces," video conferencing and virtual events that use applications like Microsoft Teams or Zoom, and enhanced communication channels (text, voice, video) that interface with immersive technologies like XR Head-Mounted Displays (HMDs). Applications leveraging video generally are resource-intensive activities, with Microsoft Teams, for instance, using around 1 Mbps to 3 Mbps per channel for conference calls with video and audio (450 MB to 1.3 GB an hour).

More complex immersive environments, such as digital twins and simulations, that provide expanded Field of View (FoV) can use more network resources as real-time data are being delivered over the network via HMDs and IoT devices, which render and manipulate high-fidelity virtual assets in real time. These applications can have high bandwidth requirements (25 Mbps to 600 Mbps) and low latency requirements (sub-30 ms) because of deploying complex real-time models and environments that can accommodate multiple users and devices in real time. Therefore, 1 hour of work for a single user with an HMD using these solutions could translate into as much as 11 GB to 270 GB.

ABI Research estimates in its *Enterprise Metaverse: Future of Work* market data (MD-EVED-102) that collaborative software and services will generate US$5 billion in revenue by 2026, accounting for a CAGR of 35%. Virtual HQs, which include Two-Dimensional (2D) and Three-Dimensional (3D) virtual office solutions and environments. will have the highest growth during the period with a CAGR of 120% and will grow from US$20 million in 2021 to over US$1 billion in 2026. Immersive collaboration solutions will also experience significant growth during the period with a CAGR of 109%, growing from US$25 million in 2021 to over US$1 billion in 2026. Finally, virtual events, which include virtual meeting spaces, webinars, conferences, etc., will increase from over US$1 billion in 2021 to over US$2.9 billion in 2026.

Chart 6: Immersive Collaboration and Related Cloud Services Revenue World Markets: 2021 to 2026

(Source: ABI Research)



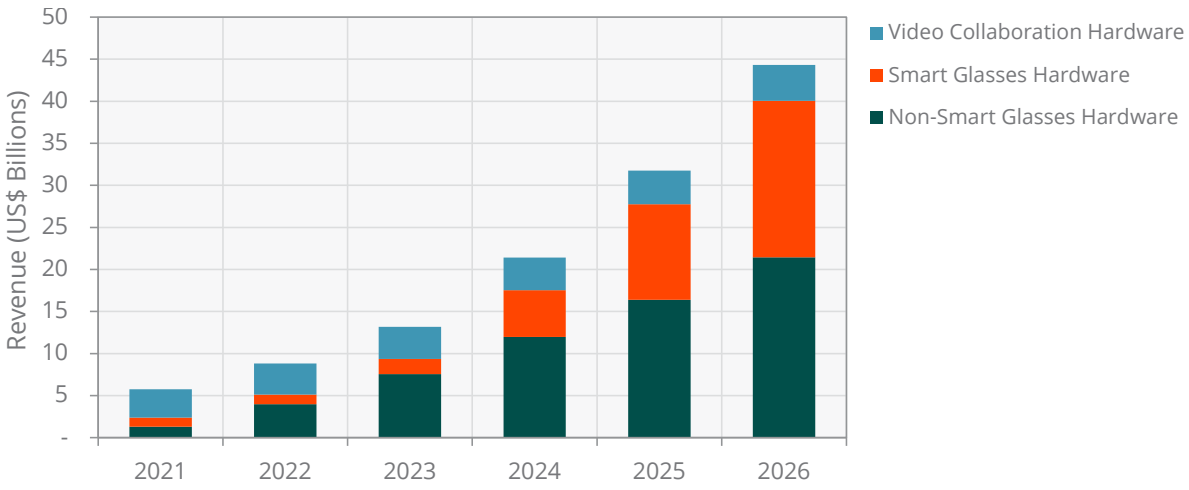
IMMERSIVE COLLABORATION HARDWARE

"Collaborative hardware" encompasses a wide spectrum of platforms, including XR equipment, video conferencing hardware, tablets, 3D printers, digital whiteboards, etc. Like standard IT network equipment, the platforms themselves do not generally contribute to network data usage, but through their software and access to online resources, can generate a large amount of network traffic. For instance, an idle or offline XR HMD would use little to no network data, but when the user connects to the cloud or an online environment with other users, the combination of equipment could generate 11 GB to 270 GB of network usage per hour. This equipment's impact on the network is highly influenced by the settings of the device (SD to UHD) and the inclusion of video. Due to the limitations of current XR technology (graphical fidelity, resolution of displays, weight of devices, etc.) and experience, most immersive use cases tend to be better suited for shorter collaborative sessions (~30 minutes), especially when using 3D environments and interactivity.

ABI Research estimates that the total enterprise immersive collaboration hardware market will reach US$44 billion in 2026, accounting for a CAGR of 50%. Smart glasses and non-smart glasses hardware will both grow at a CAGR of 76% during the period, from US$1 billion and US$1.2 billion in 2021 to US$18.6 billion and US$21.4 billion in 2026, respectively. Finally, dedicated video collaboration hardware is expected to grow from US$3.3 billion in 2021 to US$4.3 billion in 2026, accounting for a CAGR of 5%.

Chart 7: Immersive Collaboration Hardware World Markets: 2021 to 2026

(Source: ABI Research)



WORKPLACE TRAFFIC PROFILE

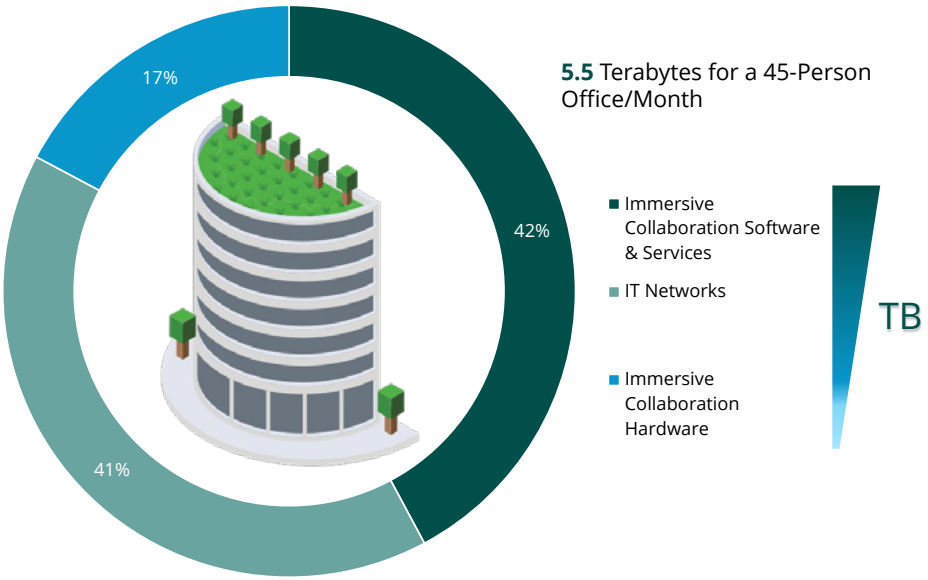
Based on analysis of the Internet data usage for different devices found in a typical office, the traffic profile is broken down into:

- IT networks
- Collaborative software and services
- Collaborative hardware

In a typical white-collar office, 5 hours of a typical workday can be spent handling activities such as email, manipulating data online, working in the cloud, managing large datasets and databases, posting online content, writing code, etc., which can potentially equate to 2.5 GB a day per user. With another hour (two 30-minute sessions) spent doing XR (11 GB) and another 2 hours spent on video conferencing calls with Microsoft Teams (2.6 GB), the total daily network use of a single employee at such an office would equate to 5.1 GB (no headset) and 16.1 GB (with headset). The global average number of people per office premises stands at 45. Based on an average of 21 workdays a month, if the office just has three immersive media headsets, the total daily network traffic load of the office would total 262.5 GB a day, equating to 5.5 TB a month. If we exclude HMDs, the office would consume 229 GB a day or 4.8 TB a month.

Figure 2: Workplace Traffic Profile—Estimated Data Usage per Month

(Source: ABI Research)



SUMMARY CONCLUSIONS

As enterprise assets become increasingly digitalized and deployed in the cloud, factors like network orchestration and security are quickly moving to the forefront of enterprise network requirements to combat corporate espionage, protect Intellectual Property (IP), and maintain a competitive advantage. In this respect, high bandwidth, low latency, security, control, and agility are all factors that are common requisites for modern enterprise networks. Alongside this, with the proliferation of devices connected to the office network, including computers, smart appliances, APs, and immersive technologies, Service-Level Agreements (SLAs) for the office network are quickly becoming more complex. As network bandwidth requirements are moving into the Gbps dimension and security and performance remain key requirements for enterprises, FTTCO is an essential and necessary networking solution that enables critical network and business activities. In this respect, future modernized enterprises in developed and developing markets will be very much tied to the continued and extensive deployment of optical fiber infrastructure.

ROLE OF FIBER IN TELCO NETWORKS

FOR TELCO NETWORKS

The shift from aging copper line networks to new fiber-optic networks has been an ongoing evolution for telco companies, as network bandwidth, durability, range, and latency become critical service components that optical fiber has proven superior at delivering. In this respect, fiber-optics are significantly faster and farther reaching than copper (reaching up to 60 Tbps and carrying data up to 100 km), making it well suited for high-performance network infrastructure. The transition to fiber-optics, however, is a tricky process that means migrating customers and commercial offerings, eliminating copper's costs, and building out fiber-optic infrastructure to maximize revenue generation and maintain profitability. Despite the challenges presented by this migration, fiber-optic network deployments have been increasing due to the wireless network evolution to 5G and 5G-Advanced in various markets. Fiber-optics are considered a key requisite in unlocking 5G, as deployment relies on fiber-optic infrastructure that transports data between mobile base stations and the physical core network at high speeds.

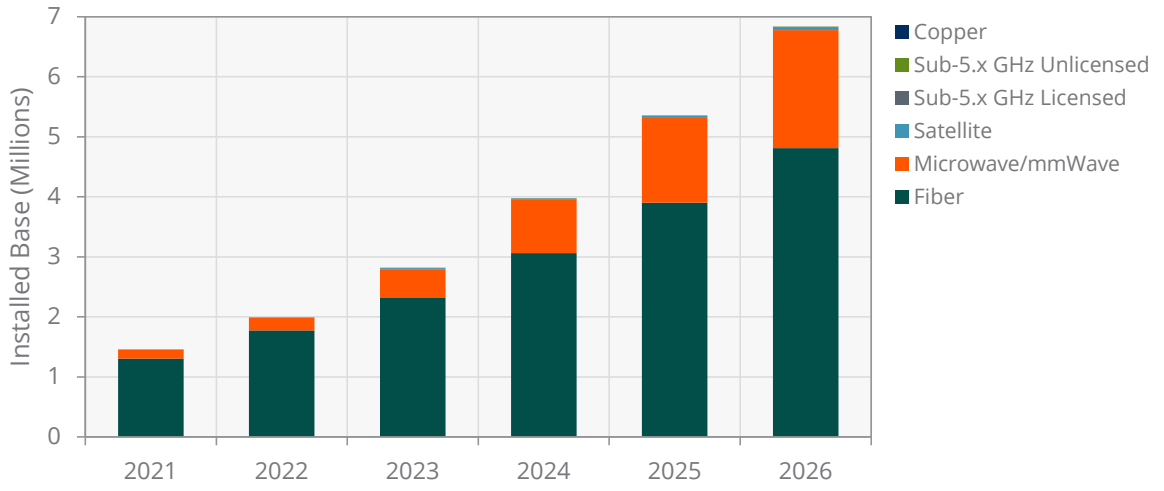
FOR 5G WIRELESS NETWORKS

5G wireless technologies bring forward more versatile connectivity scenarios with Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC) that satisfy the diverse scope of signal reliability, coverage, and network efficiency required by consumers and enterprises. By leveraging short-range, but powerful mmWave spectrum alongside a high concentration of 5G base stations (small cells and macrocells), fiber-optic infrastructure helps connect 5G infrastructure to deliver superior network throughput, bandwidth, and reduced latency to end users. In this way, 5G requires a robust fiber-optic backhaul architecture to connect the various cells of the 5G network with the physical core network and unlock mmWave's spectrum performance. To this end, to fully unlock the potential of 5G and future wireless technologies at scale, deploying fiber-optic cabling will prove invaluable.

Fiber-optics play an invaluable role in backhauling traffic from cellular telco base stations to the core network. ABI Research estimates that fiber's proportion of 5G cellular backhaul links will reach 70% or 4.8 million links by 2026, up from an estimated 1.7 million links in 2022 (see Chart 8). Fiber-optic cables have an operational lifecycle, if properly maintained, of 30 to 50 years when installed in conduit and around 25 years when hung on telephone poles (aerial fiber-optic cables). Furthermore, fiber-optic can handle more than 44 Tbps per strand, which allows fiber-optic cables to amply handle the 100 Gbps to 800 Gbps of 5G traffic a 5G cell site that a busy central business district can generate. That adoption and usage profile has the potential to accelerate.

Chart 8: ***5G Mobile Cellular Cell Site Backhaul by Type World Markets: 2021 to 2026***

(Source: ABI Research)



FIBER-TO-THE-PUBLIC EXCHANGE

Fiber-to-the-Public-Exchange (FTTPE) combines passive elements, such as fiber-optic cabling, patch panels, splice boxes, connectors, 8P8C patch cords, and active FTTPE switches to deploy GB connectivity. For some regions like Japan and the United States, demand for fiber-optics has been met with enterprise network offerings from private telecommunications operators, such as NTT and Verizon, respectively. With Verizon's Fios Business Internet, for instance, GB broadband (940/880 Mbps) is offered for US$250 a month and grew from 339,000 to 361,000 business customers (US$276 million to US$295 million) from 1Q 2021 to 1Q 2022, accounting for a CAGR of 25% and 6.9%, respectively. In this respect, fiber delivered to the premises of an enterprise or office remains popular for modern "always-on" organizations and represents between 23 EB and a peak of 109 EB worth of network traffic per month for the company.

Some of the drivers for this demand is the proliferation of data centers (nearly 8,000 in 2021), which has also been driving fiber-optic demand as capacity, quality, reliability, and speed are critical for these facilities, requiring miles of wires to interconnect IT gear, physical server racks, and other gear. When deployed at the edge or in "micro data centers" in the office, fiber-optic connections provide the most reliable and effective option for the network.

FIBER-TO-THE-CURB/FIBER-TO-THE-HOME

Fiber-to-the-Curb (FTTC) moves fiber-optic connections close to the physical premises, typically via a node within 300 Meters (m), and within range of high-bandwidth copper technologies, such as Ethernet or Wi-Fi. With Fiber-to-the-Home (FTTH), a category of Fiber-to-the-Premises (FTTP), the fiber-optic connection moves right up to the edge of the living space via an underground or aerial solution to a box on the outside wall of the home. FTTC is only a part of the fiber-optic connection, limiting its bandwidth potential when compared to FTTH, which is a full-fiber connection that brings the optical fiber closer to the subscriber and unlocks GB speeds. While FTTC connections are still present in various markets, it has been gradually phased out as governments aim to replace copper networks with full-fiber connectivity.

For telcos, FTTC serves as a stopgap or interim step to full FTTH and leverages existing twisted pair infrastructure to provide last-mile service and save on deployment costs. As a result, FTTC deployments are more likely in areas where it is uneconomic to serve FTTH. Despite this, FTTH serves as a more effective deployment method that can be deployed via a centralized split, distributed split, star, or daisy-chain architecture. This deployment method, while more expensive, can carry 1 Gbit/s data over long symmetrical connections (up to 100 Km) directly to consumer homes.

FIBER-TO-THE-ROOM

Fiber-to-the-Room (FTTR) the is next stage or progression of fiber-optics service delivery that connects a fiber-optic cable from the edge of the building into a room or multiple rooms in the home. As a delivery method, FTTR shares similar characteristics to FTTH in that deployment will be expensive when new fiber needs to be buried. In this respect, the delivery of FTTR and FTTH is predicated on existing fiber-optic infrastructure in the area and is not an on-order installation. Despite this, there is demand for FTTH and FTTR that provides some incentive for telcos to continue laying fiber to enable connectivity to more customer premises.

As a delivery method, FTTR could prove beneficial to users who need to have performance that exceeds the requirements of most modern consumer-grade devices. In this respect, the cost of installing fiber-optics throughout a building would be significant and fluctuate depending on the required length of cable, the number of drops, switches, connectors, and rooms, with an entire office building consisting of Cat5/Cat5e cabling with 100 to 200 drops estimated at between US$15,000 and US$30,000 each. Furthermore, the Internet Service Provider (ISP) will need to provide access to GB service to unlock the benefits of FTTR, which runs a per-room minimum of US$250 a month for businesses and US$65 a month for consumers in Verizon's case. The investment requirements to deploy FTTR generally regulate this method for power users or industrial applications.

If FTTR is not a viable option, fiber-optic that is run to the premises can be effectively paired with newer wireless technologies like Wi-Fi 6 (802.11ax), Wi-Fi 6E (tri-band 802.11ax), and, eventually, Wi-Fi 7 (802.11be). Fiber-optic connections can achieve higher peak data rates (over 40 Gbps, a 4X increase over Wi-Fi 6E) and tap into the network potential that fiber-optics offer.

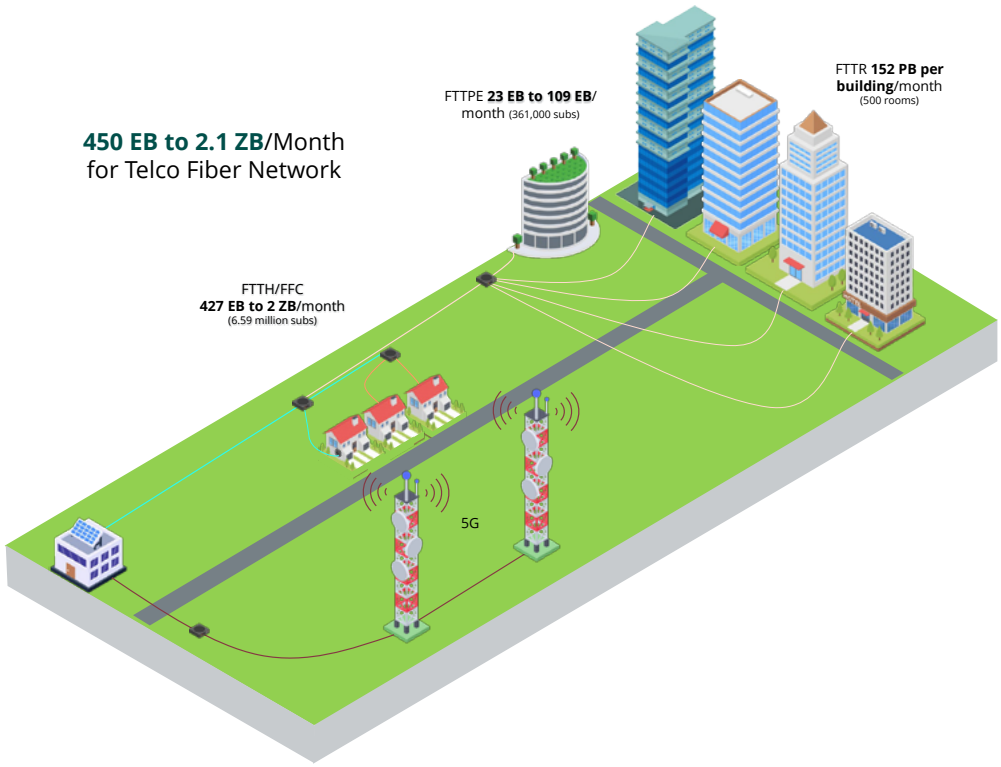
RESPECTIVE NETWORK TRAFFIC PROFILES

For FTTCO, given the network speed of Verizon's offering (200 Mbps to 940 Mbps), and the number of business users in 1Q 2022 (361,000), this represents 23 EB to a peak of 109 EB per month of total network traffic that the Verizon enterprise fiber network supports. For FTTH, given the network speed of Verizon's offering (200 Mbps to 940 Mbps), and the number of subscribers in the consumer's segment for 1Q 2022 (6.59 million), this represents between 427.4 EB and a peak of 2 ZB per month of total network traffic for the consumer segment. For FTTR, given that an office tower can have potentially 500 rooms and each room requires a GB (940 Mbps) connection, the monthly network usage would be 152 Petabytes (PB) per month for the entire building.

In these scenarios, the combined monthly total fiber-optic network traffic for a telco deploying FTTH, FTTCO, and FTTR (for 4 buildings, with 500 rooms each) would equate to between 450 EB and 2.1 ZB per month.

Figure 3: FTTX—Telco Optical Fiber Architecture Scenarios & Network Traffic Profiles

(Source: ABI Research)



SUMMARY CONCLUSIONS

Deploying fiber-optic cabling to the home, commercial office, and room is inherently tied to the existence of fiber-optic network infrastructure in the region. Alongside this, the transition to 5G and connecting mmWave base stations, antennas, and the core network requires a vast network of fiber-optic cables to ensure efficient route planning to reduce costs and overcome distance and signal loss. Even in Singapore, where an extensive nationwide fiber-optic network is already installed, additional fiber-optic cabling continues to be rolled out to ensure lower costs and efficient signal transfer (with fiber densification around 2X more than 4G). In this respect, while the fixed cost to deploy fiber-optics is high, it is necessary to enable 5G and 6G network deployments and unlock the bandwidth and network speeds that users require both at home and in the office.

FUTURE FIBER-OPTICS INNOVATIONS UNDER R&D

F5G, NEW FIBER TYPES, AND MORE

At the forefront of fixed network technology advancements are the fifth-generation fixed networks (F5G) and the transition to F5G-Advanced standards that are being defined by the European Telecommunications Standards Institute (ETSI). Development of F5G and F5G-Advanced promises significant improvements to network performance, including significant bandwidth growth (up to 800G per lambda), reduced latency (down to 1 ms), increased network scope and the number of endpoints, enhanced energy efficiency, improved trustworthiness, high-quality distributed computing networks, autonomous network management technologies, and network-based sensing. These include innovations such as fiber cable digitalization, digital twin technologies, and distributed optical fiber sensing for network-based sensing and enabling effective fiber and passive cable resource management. The improvements will unlock a variety of applications in the cloud and on the premises, such as smart factories, homes, cities, and cloud enterprise and desktop applications via Enhanced Fixed Broadband (eFBB) and full-fiber connections.

ADVANCED OPTICAL FIBER

On another front, advancements toward fifth-generation wireless technology (5G) and the trend of sending more data at high volumes are stimulating the need to achieve higher-intensity laser light through individual fibers. In this respect, demand for optical fibers that perform at higher light intensities is driving fiber specialists and materials scientists to expand beyond conventional silica fibers due to their intrinsic limitations at higher light levels. Through optical fiber doping with various compounds, such as oxides of germanium, aluminum, phosphorus, boron, fluoride, and other ions, fiber-optic manufacturers can fine-tune the refractive index of the core and cladding. This has led to the development of various advanced fiber types for different applications ranging from fibers made from fluoride glass, fluorozirconate glass, chalcogenides, or polymers. While the telecommunications industry still regards silica as king due to its relatively low cost to manufacture, the fiber-optic market's introduction of many new experimental optical fibers could lead to the adoption of specialized deployments.

WAVELENGTH-DIVISION MULTIPLEXING

Wavelength-Division Multiplexing (WDM) is a network technology that combines multiple wavelengths into a single optical fiber and enables better fiber utilization, increasing it by a factor of 16 to 96. With this technology, any mix of Ethernet, Storage Area Network (SAN), Optical Transport Network (OTN), Synchronous Optical Networking (SONET)/ Synchronous Digital Hierarchy (SDH), and native video services can be transmitted over a single optical fiber or fiber pair. With two forms of WDM, Dense Wavelength Division Multiplexing (DWDM) and Coarse Wavelength Division Multiplexing (CWDM), the technology can be deployed with different characteristics catering to different environments and user requirements. In this respect, DWDM can pack up to 96 wavelengths into a single optical fiber and is cost-effective for overcoming long distances and attenuation, making it the preferred choice for greenfield installations, and upgrading existing networks.

BEYOND F5G TECHNOLOGIES

Beyond the F5G-Advanced time frame, there are other technologies that could be considered for future fixed networks, such as multiplexing/multi-access techniques applied to Passive Optical Network (PON) architecture, spectrum slicing to the user via Ultra-Dense WDM-PON (UD-WDM-PON), a shift to Coherent (COH) detection technologies. These technologies will eventually lead to the future 6G network, which will be predicated on end-to-end converged wireline-wireless networks. These networks will span many telco network domains, from the Radio Access Network (RAN) to the core network, and even the data center. They are increasingly reliant on optical fiber communications to connect them.

FIBER NETWORK INSIGHTS & RECOMMENDATIONS

Fiber-optic technologies are a key enabler for unlocking a wide spectrum of applications, such as XR, the cloud, smart cities, digital twins, and network slicing, as well as other connectivity solutions, such as coaxial cable TV, satellite, mobile, and FWA. The largest barrier to fiber-optic deployments, however, is the cost associated with laying new fiber and maintaining it. In this respect, the capital outlay per subscriber is the highest of all broadband access solutions, at US$4,500. The next most costly technology is satellite broadband deployments, which are estimated at US$3,000 per subscriber. Alongside this, lower fiber-optic broadband Average Revenue per User (ARPU) at roughly US$65 per month means that the Return on Investment (ROI) will take longer than some other deployments. This creates an urgency to monetize new fiber installations as quickly as possible.

On the other hand, fiber-optics reign supreme when it comes to providing the high-bandwidth low-latency network connection required for GB speeds and microwave and mmWave band solutions. In this respect, the data transfer rate of a single fiber-optic link exceeds around 40 Tbps, with the next fastest solution being 5G, which clocks in at 20 Gbps—a 2,000X difference. Optical fiber infrastructure can unlock significant growth opportunities for businesses and consumers through direct fiber-optic connections and 5G and is invaluable for digital economy development, not just in developed markets but also in emerging markets. Integrating and expanding fiber-optic networks should be a high priority for Communication Service Providers (CSPs), which should focus on maximizing fiber ROI throughout every stage of the deployment process, while reducing the impact of the transition from copper.

Several key areas to help achieve this goal include:

- Plan for the long-term expansion of 5G and other new applications. This includes upgrading and replacing existing fiber-optic network infrastructure, which will require significant investment.
- Move many customers to fiber-optics (from copper) simultaneously, particularly those being served by the same telco public exchange. The public exchange incurs high costs from maintenance, network technology management, building, and lease costs.
- Charge higher fees for copper solutions, reduce maintenance, and prevent copper line subscriptions for networks slated for decommissioning.
- Coordinate with local governments to acquire subsidies and grants for the proactive transition to fiber-optics and deployment of network infrastructure for 5G and other wireless technologies.

SUMMARY CONCLUSIONS

Innovations in fiber-optic technologies are critical for unlocking the evolution of new wireless and wired networks. Significant drivers for this transformation are industry-wide trends, such as the cloudification of applications, the need to improve the network itself, and the transition from copper network infrastructure to full-fiber deployments. The evolution of fiber-optic technologies involves not only the introduction of new optical fiber types, but the inclusion of optical sensors, AI, ML, and network slicing to maximize network resource deployments for a variety of use cases. These improvements in fiber-optic technologies will allow modern networks to unlock greater security, speed, efficiency, and intelligence than what was possible before.

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