APEX STANDARDS

Standardization and Security: The Impact of PON on Digital Infrastructure

Passive Optical Network (PON) is a fiber-optic access network technology that offers a cost-effective and scalable solution for providing high-speed broadband access to homes and businesses. Utilizing optical splitters, a single optical fiber is divided into multiple wavelengths or channels, with each channel carrying a separate data signal.

Advantages of PON include:

- High capacity: PON can support up to 100 Gbps of bandwidth per fiber, which is more than enough to meet the the growing data rates, traffic requirements, and the needs of even the most demanding users.

- Scalability: More optical splitters can be added to expand capacity for broadband service as demand grows. PON can be easily upgraded to support higher data rates, making it future-proof for evolving network services.

- Reliability: Fiber-optic cables used in PONs are less susceptible to interference and signal degradation than copper-based technologies. PON systems are designed with redundancy to minimize the impact of outages.

- Energy efficiency: Since PONs use passive optical components like splitters and combiners, they require less power than active components. This results in lower energy consumption and reduced operational costs.

- Cost-effectiveness: PONs offer cost-effectiveness by supporting multiple services such as residential broadband, business connectivity, and network backhaul. Consolidated infrastructure results in saved deployment and maintenance costs, as initial investment in PON equipment can be offset by long-term savings in operational costs.

The International Telecommunication Union (ITU) spearheads PON technology standardization through Study Group 15. By developing a series of recommendations and standards, ITU ensures global interoperability, reliability, and cost-effectiveness of PON systems **Table 2**.

The Institute of Electrical and Electronics Engineers (IEEE) is also actively involved in PON-related standardization under the 802.3 wired Ethernet efforts, such as 10BASE-T, 100BASE-TX, and 1000BASE-T. ITU and IEEE collaborate closely to ensure seamless compatibility and synchronization between their respective standards, facilitating the development of next-generation PONs.

The 3rd Generation Partnership Project (3GPP) plays a crucial role in the mobile communication sector by developing and defining standards for various generations of mobile networks, such as GSM, UMTS, LTE, and 5G. For example, 3GPP Release 15 (2018) and subsequent releases define the standards for 5G networks, in which XGS-PON can be used as a backhaul technology. Key 3GPP aspects related to PON are:

- Network architecture: 3GPP defines the overall architecture of mobile networks, including core network elements, radio access networks, and the transport layer. This helps in understanding how PON technology can be integrated into mobile networks.

- Transport network requirements: As mobile networks evolve and demand higher data rates and lower latency, 3GPP specifies the transport network requirements for various generations of mobile networks, such as 4G LTE and 5G NR. These requirements help in determining the suitability of PON for meeting the needs of advanced mobile networks.

- Network synchronization and timing: 3GPP standards address the need for accurate synchronization and timing in mobile networks, which is essential for providing high-quality services and maintaining network stability, thus making PON a suitable choice for mobile backhaul and fronthaul networks.

While 3GPP primarily focuses on mobile telecommunications, it recognizes the importance of PON in the mobile communication sector in recent TDoc discussions. By defining requirements and architectures for mobile backhaul and fronthaul networks, 3GPP sets the stage for the integration of PON technology in advanced mobile networks, helping to address the increasing demand for capacity, scalability, and low latency.

The global PON market is anticipated to grow at a compound annual growth rate (CAGR) of 12% through 2030, as driven by rising demand for high-speed broadband, the growing popularity of fiber-to-the-home (FTTH) and Fiber-to-the-Business (FTTB) applications and decreasing PON equipment costs **Table 1**.

PON has implications for national security. On one hand, it provides a robust infrastructure for improved communication and information sharing among security agencies. On the other hand, it raises concerns about data privacy and network vulnerabilities as more data is transmitted over these networks. It is crucial for governments and stakeholders to address these challenges, ensuring PON remains secure, reliable, and privacy-conscious.

PON has become a strategic asset in the mobile communication sector, driving the development of smart cities, IoT ecosystems, and advanced mobile networks. Addressing national security and data privacy challenges, PON shapes the digital landscape.

As a vital component in telecommunications, PON contributes to efficient broadband access and fosters innovation with market growth, standardization, and partnerships with ITU, IEEE, and 3GPP. Collaboration among the private sector and governments is crucial. The private sector should invest in R&D and strategic alliances, while governments incorporate PON into their digital infrastructure strategies, encouraging cross-sector cooperation for a secure and thriving future. ∎

COUNTRY	COMPANY	MAJOR PRODUCT	CATEGORY	SPEED	TECHNICAL	2000	2005	2010	2015	2020
UNITED STATES	Cisco	NCS 540 Series	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	-	15%
UNITED STATES	ADTRAN	TA1200 Series	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	-	12%
FINLAND	Nokia	1830 PSS	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	7%	11%
JAPAN	NTT Electronics	PA5OLINK NEO	Backhaul, Data Center	Up to 10Gbps	DWDM	-	-	3%	6%	10%
UNITED STATES	Calix	AXOS E7-2	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	5%	10%
JAPAN	Fujitsu	FLASHWAVE 9500	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	4%	6%	8%
GERMANY	ADVA Optical Network	FSP 3000	Backhaul, Data Center	Up to 100Gbps	DWDM	-	1%	3%	5%	8%
CHINA	Huawei	OSN 1800	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	4%	8%
JAPAN	NEC Corporation	SpectralWave	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	3%	5%	7%
ITALY	SIAE Microelettronica	SM-Optics	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	4%	7%
CHINA	Huawei	OptiX OSN 8800	Backhaul, Data Center	Up to 100Gbps	DWDM/OTN	-	-	2%	4%	7%
JAPAN	Fujitsu	FLASHWAVE 9500	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	2%	4%	7%
UNITED STATES	Cisco	Catalyst 4500-X	Backhaul, Data Center	Up to 10Gbps	Ethernet	-	-	2%	4%	6%
CHINA	Huawei	OptiX OSN 9800	Backhaul, Data Center	Up to 200Gbps	DWDM/OTN	-	-	-	3%	6%
INDIA	Tejas Networks	TJ1400	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	1%	3%	6%
UNITED KINGDOM	BTI Systems (now part of Juniper Networks)	7800 Series	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	1%	3%	5%
UNITED STATES	Cisco	Catalyst 3850	Backhaul, Data Center	Up to 1Gbps	Ethernet	-	-	1%	3%	5%
CHINA	ZTE	ZXONE 9700	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	2%	5%
FRANCE	Ekinops	360 Platform	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	2%	4%
ISRAEL	ECI Telecom (now part of Ribbon Comm.)	Apollo	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	2%	4%
CHINA	ZTE	ZXONE 9700	Backhaul, Data Center	Up to 100Gbps	DWDM/OTN	-	-	1%	2%	4%
CHINA	Huawei	OptiX OSN 6800	Backhaul, Data Center	Up to 40Gbps	DWDM/OTN	-	-	1%	2%	3%
CHINA	ZTE	ZXMP M721	Backhaul, Data Center	Up to 100Gbps	DWDM/OTN	-	-	-	1%	3%
ITALY	Aethera Networks	MISTRAL	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	3%
JAPAN	NEC	SpectralWave DW7000	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	3%
CANADA	Telco Systems	T-Marc 3348	Backhaul, Data Center	Up to 10Gbps	Carrier Ethernet	-	-	-	1%	2%
CHINA	Raisecom	ISCOM6800	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	2%
UNITED KINGDOM	Aethos Communications	X Series	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	2%
ISRAEL	PacketLight Networks	PL-1000TE	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	1%
CANADA	Nortel (defunct)	OPTera Metro 5100	Backhaul, Data Center	Up to 10Gbps	DWDM	13%	4%	-	-	-
CANADA	Nortel (defunct)	OPTera Metro 5200	Backhaul, Data Center	Up to 40Gbps	DWDM	-	2%	-	-	-
CANADA	EXFO	FTBx-88460	Backhaul, Data Center	Up to 100Gbps	DWDM	-	-	-	1%	3%
CHINA	Huawei	MA5800 Series	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	5%	15%	25%
CHINA	ZTE	ZXA10 C300	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	3%	10%	20%
UNITED STATES	Cisco	ME 4600 Series	Residential, Business	1Gbps, 10Gbps	GPON, XG-PON1	-	-	-	15%	18%
UNITED STATES	ADTRAN	TA5000 Series	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	10%	12%	14%
FINLAND	Nokia	7360 ISAM FX	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	5%	10%	14%
UNITED STATES	Calix	E-Series	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	6%	9%	11%
SWEDEN	Ericsson	EDA 1500	Residential, Business	1Gbps, 10Gbps	GPON, XG-PON1	-	-	-	8%	11%
CHINA	Huawei	MA5600T	Residential, Business	Up to 2.5Gbps	GPON	-	2%	5%	8%	10%
CHINA	ZTE	ZXA10 C300	Residential, Business	Up to 2.5Gbps	GPON	-	1%	4%	6%	8%
SOUTH KOREA	Samsung	Smart-OLT	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	1%	4%	8%
CHINA	Huawei	SmartAX MA5680T	Residential, Business	Up to 2.5Gbps	GPON	-	1%	3%	5%	7%
UNITED STATES	Cisco	ME 4600 Series	Residential, Business	Up to 2.5Gbps	GPON	-	1%	3%	5%	7%
TAIWAN	Zyxel	IES5206M	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	4%	7%
CHINA	FiberHome	AN5516-01	Residential, Business	Up to 2.5Gbps	GPON	-	-	2%	4%	6%
CHINA	Huawei	MA5800-X15	Residential, Business	Up to 10Gbps	XG-PON	-	-	2%	4%	6%
CHINA	ZTE	ZXA10 C320	Residential, Business	Up to 2.5Gbps	GPON	-	-	2%	4%	6%
UNITED STATES	DASAN Zhone Solutions	ZNID-GPON-26xx	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	3%	6%
JAPAN	NTT Electronics	NEL GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	1%	2%	3%	5%
CHINA	UTStarcom	TN765	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	3%	5%
CHINA	ZTE	ZXA10 C600	Residential, Business	Up to 10Gbps	XG-PON	-	-	1%	3%	5%
CHINA	FiberHome	AN5516-01	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	-	2%	5%
SOUTH KOREA	LG Uplus	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	2%	5%
SPAIN	Telnet Redes Intel.	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	2%	4%
CHINA	Alphion	AOLT-4000	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	2%	4%
SOUTH KOREA	LG Uplus	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	2%	4%
JAPAN	Sumitomo Electric	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	1%	1%	2%	4%
SOUTH KOREA	Dasan Networks	V5812G Series	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	4%
UNITED STATES	Broadcom	BCM68620	Residential, Business	Up to 10Gbps	XGS-PON	-	-	-	-	3%
JAPAN	Mitsubishi Electric	MELX GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	2%	3%
SOUTH KOREA	KT Corporation	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	1%	2%	3%
CHINA	Dasan Zhone	MXK-F1421	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	3%
GERMANY	Keymile	MileGate 2510	Residential, Business	1Gbps, 10Gbps	GPON, XG-PON1	-	-	-	1%	3%
TAIWAN	Edgecore Networks	ASXvOLT16	Residential, Business	Up to 10Gbps	XGS-PON	-	-	-	1%	3%
CHINA	Raisecom	ISCOM5508-GP	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	2%
FRANCE	Sagemcom	AXIOME GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	2%
INDIA	UTL Technologies	UTL GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	2%
ISRAEL	RAD	ETX-2i	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	-	1%	2%
ITALY	PBN	AIMA3000	Residential, Business	Up to 10Gbps	GPON, XGS-PON	-	-	-	1%	2%
JAPAN	Oki Electric	GPON OLT	Residential, Business	Up to 2.5Gbps	GPON	-	-	-	1%	2%

Table 1 presents the top PON products sorted by global market share (2000-2020). Leading suppliers Huawei, Nokia, and ZTE dominate consistently. Behind these frontrunners, Cisco, ADTRAN, NTT Electronics, and Calix also excel in the data center sector. In the residential market, ADTRAN, Calix, Ericsson, and Samsung follow the top three closely. In the latest XGS-PON market, Huawei, ZTE, Cisco, ADTRAN, and Nokia emerge as best-sellers. For the DWDM-PON category, which offers extended signal distance, Huawei, Cisco, ZTE, ADTRAN, Nokia, and Fujitsu take the lead. These rankings reveal a dynamic market landscape with Huawei and ZTE making significant advancements in both categories over time.

PON Type	Speed	Related ITU Standards Working Group	Related IEEE Standards Working Group	Related 3GPP Standards Working Group	New Capabilities	New Industrial Applications	Key Standardization Contributors	Major Standard-related Product Suppliers Ordered by Market Share	ITU Approval Year
APON (155 Mbps)	Up to 622 Mbps downstream and 155 Mbps upstream	ITU-T G.983	IEEE 802.3ah	-	Low Cost, Simplified Architecture, Passive Optical Splitters	Broadband services	Alcatel (FR), Nortel (CA), Lucent (spinoff AT&T), Fujitsu (JP), Mitsubishi (JP), Ericsson (SE)	Alcatel (FR), Fujitsu (Japan), Lucent (spinoff AT&T), NEC (Japan), Ericsson (Sweden)	1995
BPON (622 Mbps)	Up to 2.5 Gbps downstream and 622 Mbps upstream	ITU-T G.983	IEEE 802.3ah	-	Low Cost, Simplified Architecture, Passive Optical Splitters	Broadband services			1998
E-PON (1G-PON Symmetrical)	Up to 1 Gbps downstream and 1 Gbps upstream	ITU-T G.984	IEEE 802.3ah	3GPP 3G Release 5	Low Cost, Simplified Architecture, Passive Optical Splitters	Broadband, telephony, IPTV	Alcatel-Lucent (FR), Nokia (FI), Broadcom (US), Huawei (CN), ZTE (CN), Sumitomo (JP), Ericsson (SE)	Nokia (FI), Huawei (CN), ZTE (CN), Alcatel-Lucent (FR), Calix (US), Sumitomo (JP)	2004
XG-PON1 (10G-PON)	Up to 10 Gbps downstream and 2.5 Gbps upstream	ITU-T G.987	IEEE 802.3av	3GPP LTE Release 10	Dynamic Bandwidth Allocation, Wavelength Division Multiplexing (WDM), TDM-PON Support	Business services, mobile backhaul, smart grid	Nokia (FI), Huawei (CN), Broadcom (US), ZTE (CN), Sumitomo (JP), Mitsubishi (JP), NEC (JP), Adtran (US)	Huawei (CN), Broadcom (US), ZTE (CN), Sumitomo (JP), Mitsubishi (JP), NEC (JP)	2010
XG-PON2 (10G-PON)	Up to 10 Gbps downstream and 2.5 Gbps upstream	ITU-T G.987.2	IEEE 802.3av	3GPP LTE-Advanced Release 11	Dynamic Bandwidth Allocation, Wavelength Division Multiplexing (WDM), TDM-PON Support	Fiber to the Home (FTTH), Fiber to the Building (FTTB), Fiber to the Curb (FTTC)	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Sumitomo (JP), Mitsubishi (JP), NEC (JP), Adtran (US)	Huawei (CN), ZTE (CN), Broadcom (US), (CN), Sumitomo (JP), Mitsubishi (JP), NEC (JP), Adtran (US)	2011
Coexistence and migration technologies	-	G.98x series	-	-	Solutions that facilitate the coexistence of different PON generations on the same infrastructure, allowing service providers to migrate their networks cost-effectively.	-	-	-	2014
Software-defined PON (SD-PON)	-	SD-PON is a concept that can be applied to any PON technology	-	-	Centralized control, network programmability, and dynamic resource allocation for PON networks, enabling efficient network management and optimization.	-	-	-	2015
XGS-PON (10G-PON Symmetrical)	Up to 10 Gbps downstream and 10 Gbps upstream	ITU-T G.9807.1 ITU-T G.9807.2	IEEE 802.3av	3GPP LTE-Advanced Pro Release 13 (CT1) TS 24.229; TR 21.866	Coexistence with GPON and XG-PON, Flexible Bandwidth Allocation, Support for NG-PON2	Business services, mobile backhaul, 5G x-haul	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Sumitomo (JP), Adtran (US), Ericsson (SE), Calix (US)	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Sumitomo (JP), Adtran (US), Calix (US) Broadcom (US)	2016
NG-PON (40G-PON)	Up to 40 Gbps downstream and 10 Gbps upstream	ITU-T G.989.1 ITU-T G.989.2	IEEE 802.3bq	3GPP 5G Release 14 (CT1) TS 24.229; TR 21.866 (SA1) TR 22.821	Support for Both TDM and WDM PON, Enhanced Network Reliability, Power Saving, Support for Higher Split Ratios	Business services, mobile backhaul, 5G x-haul, smart home	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Ericsson (SE), Adtran (US), Innolight (CN), Calix (US)	Huawei (CN), Nokia (FI), ZTE (CN), Calix (US), Fiberhome (CN), Adtran (US), Broadcom (US), Innolight (CN)	2017
NG-PON2 (40G-PON)	Up to 40 Gbps downstream and 10 Gbps upstream	ITU-T G.989.2 ITU-T G.989.3	IEEE 802.3bs	3GPP 5G Release 15 RAN TR 37.880 (CT1) TS 24.229; TR 21.866 (SA1) TS 22.104; TS 23.745	Support for Both TDM and WDM PON, Coexistence with GPON, XG-PON, and XGS-PON, Enhanced Network Reliability, Power Saving, Support for Higher Split Ratios	High-capacity services, 5G x-haul, smart building	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Ericsson (SE)	Huawei (CN), Nokia (FI), ZTE (CN), Nokia (FI), Calix (US), Fiberhome (CN)	2018
50G-PON	Up to 50 Gbps downstream and 25 Gbps upstream	ITU-T G.9804.3	IEEE 802.3ca; IEEE P802.3cd; IEEE P802.3cg	3GPP 5G Advanced/6G Release 17 (CT3) TS 29.561; TS 29.514 (SA6) TR 23.745 (CT1) TS 24.229	Support higher bandwidth, improved scalability, enhanced efficiency, lower latency, advanced network slicing, and increased reliability, enabling better support for data-intensive applications, IoT, and 5G networks.	5G+/6G x-haul, smart city, smart grid, autonomous driving, remote sensing, industrial automation, smart logistics, digital health	Huawei (CN), Nokia (FI), ZTE (CN), Broadcom (US), Ericsson (SE), Adtran (US), Innolight (CN), Calix (US)	Huawei (China), Semtech (chip only, US)	2021

Table 2 In a rapidly evolving Passive Optical Network (PON) market, companies like Huawei, Nokia, and ZTE consistently lead in supplying PON solutions. PON technology has evolved from APON (155 Mbps) in 1995 to 50G-PON in 2021, with improved bandwidth, latency, and intelligence supporting diverse service scenarios like home, government, enterprise, campus, and industrial internet. ITU-T released 50G PON as the next-gen PON standard in September 2021. The industry's first commercial 50G PON solution was released by Huawei at MWC in February 2023 for ultra-broadband access, supporting full services and smooth evolution to F5.5G. Semtech, a US firm with a core focus on signal integrity and optical communications, demonstrated the world's first 50G-PON compliant chipset at OFC in March 2023, expanding their PON-X platform for multi-gigabit Fiber-to-the-X applications.