ZTE

White Paper on 50G PON Technology

V2.0

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1 PON Technology Review and 50G PON Technology Outlook

1.1 History of PON Development

Passive optical network (PON) technology is a passive broadband access technology that uplinks and downlinks data with different wavelengths, and uses time-division multiplexing technologies for data transmission. A passive optical network utilizes a point-to-multipoint (P2MP) topology, where a plurality of optical network units (ONUs) are connected to the same PON port to save central office resources. The ODN connecting the OLT and ONUs uses optical fibers and passive components to avoid electromagnetic interference, effects of Lightening and provide strong environment adaptability as well as easy expansion and upgrade. PON technology has been applied on a large scale due to its advantages of high bandwidth, high reliability, multi-service transmission, and low cost.

ITU-T/FSAN and IEEE have played a significant role in promoting the development of PON technologies. PON developed from the first ATM PON (APON) and then evolved in Broadband PON (BPON). The commercial PON technologies have experienced three generations of development, among which GPON and EPON have been commercially deployed on a large scale. At present, 10G-EPON and XG(S)-PON technologies have already matured and enter the window period of large-scale commercial use.

Table 1-1 Evolution of PON Technologies

Generation of PON Technology	Downlink Rate	IEEE	ITU-T
GPON/EPON	2.5 Gbps/1.25 Gbps	EPON (IEEE 802.3ah)	GPON (ITU-T G.984)
10G PON	10 Gbps	10G-EPON (IEEE 802.3av)	XG-PON (ITU-T G.987) XGS-PON(ITU-T G.9807)
50G PON	25G/50Gbps	25G/50G-EPON (IEEE 802.3ca)	50G PON (ITU-T G.9804)

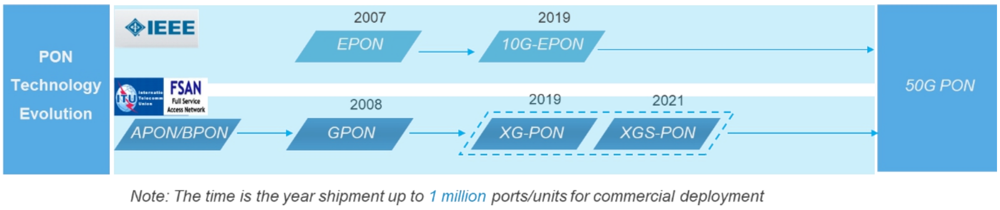
The first-generation GPON/EPON technology can provide 100 Mbps-capable bandwidth to users, and gradually replace the existing copper cable access technology such as old PSTN/TDM and DSLAM networks. The second-generation 10G PON technology can provide 1 Gbps bandwidth to users, which satisfies the large-scale application of 4K/8K video services and the introduction of VR/AR services in the early stage. The services requiring a bandwidth of more than 1G, such as extreme AR, government and enterprise access and 5G xHaul, propose higher requirements for the bandwidth and latency of PON technologies.

The next-generation PON (NG-PON) following 10G PON has two development directions. The first direction is to improve the single-wavelength rate and the second direction is to increase the total rate through multi-wavelength multiplexing. It is widely recognized in the industry that the capacity of the next-generation optical access network will be increased to 50 Gbps. Therefore, how to upgrade the system capacity in a simple and efficient manner becomes a research hotspot in the PON field. Based on this idea, IEEE and ITU-T are studying and actively promoting the follow-up evolution of PON technologies.

IEEE was the first to start the formulation of the NG-PON standard, which supports a downstream rate of 25 Gbps over a single optical fiber, an upstream rate of 10 Gbps or 25 Gbps rate, and compatibility with 10G-EPON. To address the 50 Gbps bandwidth requirements, it employs the multi-wavelength multiplexing technology and channel binding technology to provide two 25 Gbps channels to achieve a transmission rate of 50 Gbps.

Based on the technical research report of the G.Sup64 PON transmission technologies above 10 Gb/s per wavelength, ITU-T takes into account the requirements of home users, enterprise users, mobile backhaul and fronthaul, and gradually sets requirements for NG-PON, focusing on the 50G PON technology with a single channel rate of 50 Gbps.

Fig. 1-1 PON Technology Evolution Diagram

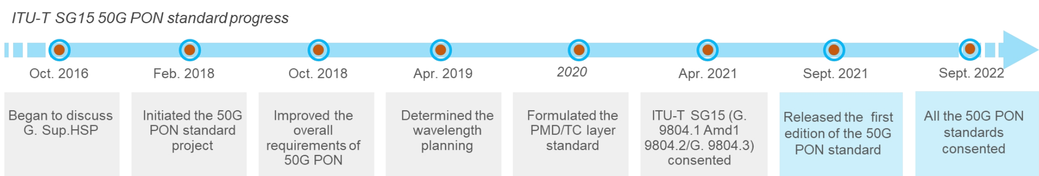


1.2 50G PON Standards Development

After completing the formulation of the 10G GPON standard, specified as the XG-PON standard, FSAN started the technical research of NG-PON, which initially has multiple wavelengths, each operating at 10 Gbps. The NG-PON2 standard research was initiated in 2011, and was formulated in 2015. Restricted by the high cost of tunable optical components and system maturity, NG-PON2 has seen slow and few commercial deployment, and its future applications are doubtful, therefore it may be skipped.

At the same time, ITU-T has carried out research on the subsequent evolution of PON technologies, and initiated the white paper of the next-generation high-speed PON technology to investigate its various technical possibilities. Compared with the multi-wavelength multiplexing solution, the single-wavelength 50G PON has the potential to become the mainstream industrial standard of the next-generation optical access network after 10G PON. In 2018, ITU-T/ FSAN started the formulation of the 50G PON standard *G.HSP: G. Higher Speed PON*. ITU-T determined 50G PON as the development direction of the next-generation PON technology after 10G PON in 2018, released the first version of the 50G PON standard in September 2021, and consented the first amendment of 50G PON (Amd1) in September 2022.

Fig. 1-2 50G PON Standards Development



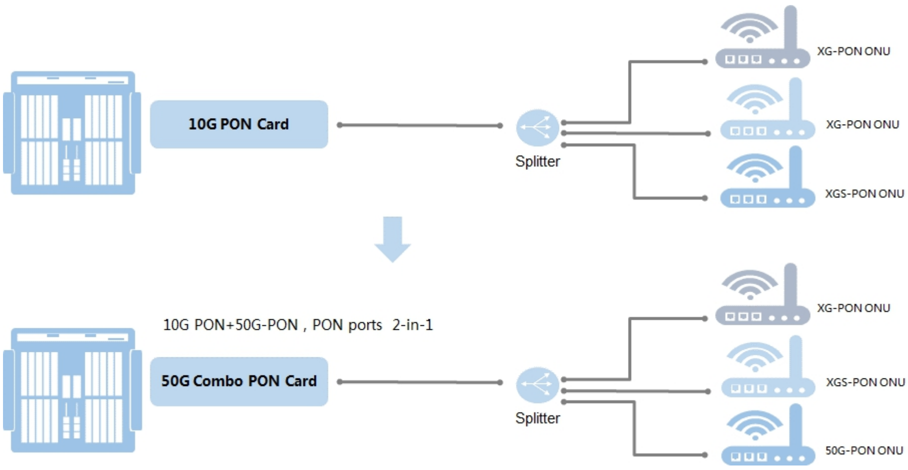
The research on single-wavelength 50G PON has also been carried out. Both the upstream and downstream of the 50G PON operate in the O band. The FEC adopts the LDPC error correction algorithm. In order to better support low latency, 50G PON introduces the dedicated activation wavelengths (DAW) and CoDBA. With the DAW technology, ONUs are registered and activated on dedicated wavelengths, and service wavelengths are not allocated with a quiet window, reducing the transmission delay caused by registration window opening. CoDBA means that the OLT allocates authorization bandwidth to the ONU through the coordination with the base station when carrying wireless services. The time when the mobile terminal data reaches the ONU is the DBA authorization time of the PON system. The data can be forwarded without waiting, thus reducing the delay caused by bandwidth scheduling.

1.3 Migration to 50G PON

At present, 10G PON has entered the batch deployment phase. With the rapidly growing demands for home broadband access and government & enterprise access in the future, 50G PON will be the next deployment trend of wireline broadband access. In order to implement smooth migration from 10G PON to 50G PON and meet the networking requirements of different services, 10G PON and 50G PON will coexist for a long time. To save the deployment space of the equipment room, reduce energy consumption of optical access equipment, effectively use the ODN resources of the existing network, and reduce the operators’ network construction costs, the multi-mode optical transceiver module, such as Combo PON optical module in support for the coexistence of GPON and 10G PON, has been proved to be the most effective means so far.

According to the requirements for smooth network evolution, equipment room deployment space saving and efficient utilization of ODN resources, it is necessary to verify and test the coexistence of 50G PON and 10G PON services.

Fig. 1-3 Smooth Migration and Evolution to 50G PON



2 50G PON Requirement Analysis

The increasing demand for access bandwidth requires continuous improvement of the access network capacity. The development goal of the optical access network in 5-10 years is to increase the access rate per subscriber to 1-10 Gbps. In addition, with the full deployment of 5G, new scenarios such as small 5G small cells emerge. Compared with the direct optical fiber connection solution, PON-based 5G Fronthaul can greatly save feeder optical fibers. Therefore, both the fixed networks and 5G mobile access networks have potential requirements for implementing the ultra-10G optical access technology. 10G PON has been deployed on a large scale, and the market needs to focus on and deploy next-generation technologies to meet network evolution requirements. The follow-up evolution of 10G PON requires more than a four-fold increase in bandwidth, smooth evolution, and compatibility with the existing ODN.

50G PON is the next-generation PON standard formulated by ITU-T after 10G PON. It supports 50 Gbps uplink and downlink over a single wavelength, and provides a bandwidth five times faster than 10G PON. It still uses the TDM PON mechanism, and supports the coexistence with 10G PON and the deployed ODN infrastructure. In addition, in view of the features of intelligent new services, it improves low latency, slicing, energy saving, and reliability to meet the subsequent smooth evolution of 10G PON and meet the comprehensive access requirements of multiple scenarios while considering costs.

The general requirements of 50G PON have been released, and are specified in terms of transmission capability, coexistence, service support, protection and security.

2.1 Bearer Capability Requirements

Requirements for all the 50G PON systems intended to run on a PON infrastructure based on optical splitters:

- In the downlink and uplink directions, the nominal symmetrical rate of each wavelength channel is 50 Gbps to support a maximum service rate of at least 40 Gbps.
- The asymmetric nominal rate of each wavelength channel is 50 Gbps uplink and 25 Gbps downlink.
- Supports ONUs with different upstream nominal rate on the same wavelength channel through TDMA.
- Supports the optical fiber types described in ITU-T G.652 and ITU-T G.657.
- Operates on the ODN composed of optical fibers, connectors, splitters and wavelength selectable equipment.
- The TDMA-based system should support:
  - A maximum optical fiber coverage distance of 60 km.
  - A maximum differential fiber length of 40 km.
  - A minimum optical splitting ratio of 1:256.

2.2 PON Coexistence Requirements

The coexistence requirements for the 50G PON technology are as follows:

- Supports coexistence of traditional PON and 50G PON technologies over the same optical fiber.
- Avoids or minimizes the interruption of ONU services that not upgraded.
- Supports compatibility with traditional PON services.

Two steps can be considered in the migration from the existing network to 50G PON: from GPON to XG(S)-PON, and from XG(S)-PON to 50G PON. This requires to migrate GPON under the PON port to XG(S)-PON before upgrading it to 50G PON. The GPON wavelength window is reused so that 50G PON and XG(S)-PON can coexist and implement full migration in two steps. In this case, the two types of PON technologies coexist at any time.

In order to enable simultaneous operation of XG(S)-PON and 50G PON, the network should have the WDM functionality, provided by either independent CEx or 50G PON Combo PON optical modules, see Fig. 2-1 and Fig. 2-2.

Fig. 2-1 Coexistence of XG(S)-PON and 50G PON via Independent CEx

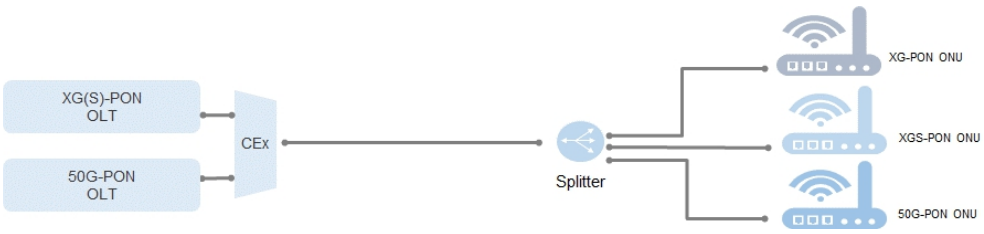
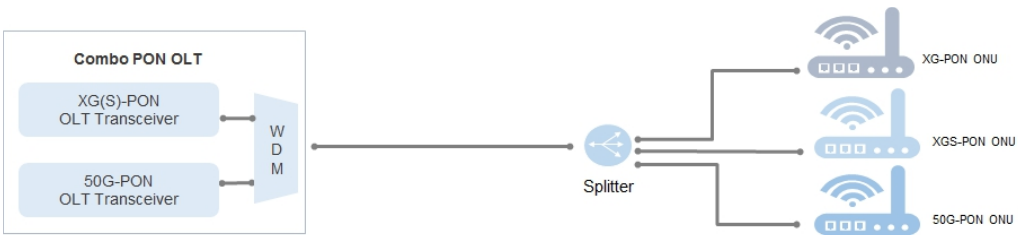


Fig. 2-2 Coexistence of XG(S)-PON and 50G PON via Combo PON



2.3 Service Support Requirements

With high service quality and high bit rate capability, the 50G PON system fully supports the various service requirements of home users, enterprise and campus users. Moreover, the 50G PON system can achieve better delay and jitter performance. 50G PON must support traditional services, such as using POTS and T1/E1 emulation, high-speed dedicated line (with frame and without frame) and new packet services, and must support Ethernet packets with up to 9,000 bytes.

For mobile backhaul services (especially 5G services), it should support time transfer (such as ITU-T G.984, ITU-T G.987, ITU-T G.989 and ITU-T G.9807 series) and low transmission delay.

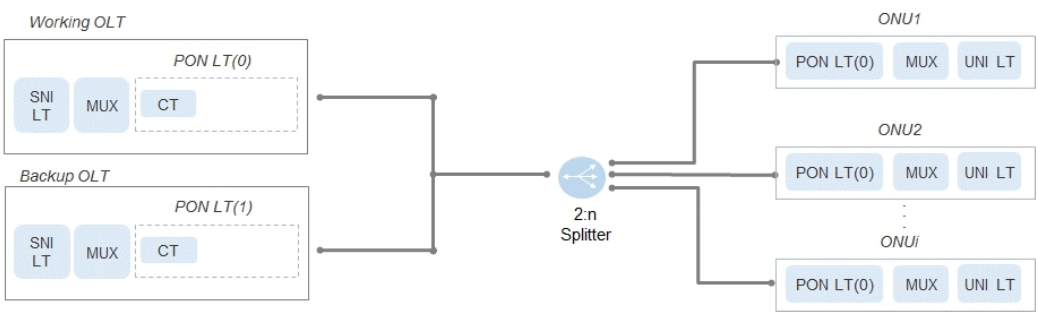
To support wireless transmission requirements, including OTDOA-based location service, the 50G PON ONUs should keep the ToD synchronized to the precision of about 100ns specified in ITU-T G.8273.2.

2.4 Protection Requirements

50G PON protection will become more and more important in supporting enterprise applications and high-value home user applications, especially in the multi-service coexistence scenarios. 50G PON needs to provide end-to-end protection to avoid service interruption to thousands or even tens of thousands of users when optical fibers or devices are faulty. The protection mode can be Type B or Type C.

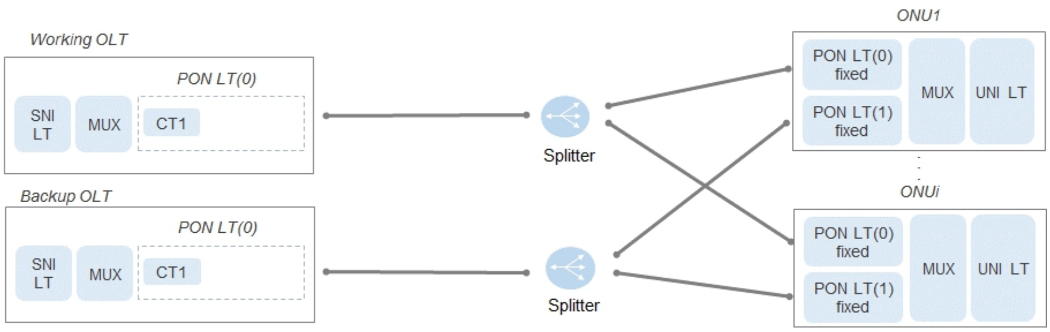
When Type B protection is adopted, the OLT and feeder fibers will be protected, see Fig. 2-3.

Fig. 2-3 Type B Protection - 1:1 Redundancy



When Type C protection is adopted, that is, the duplex system (1+1 model), the ONU has two fixed transceivers, see Fig. 2-4. Therefore, the fault can be recovered at any time after the standby OLT is switched over.

Fig. 2-4 Type C Protection - 1:1 Redundancy



2.5 Security Requirements

Like the traditional PON system, 50G PON is based on shared media. All ONUs on the same PON receive complete data. Therefore, measures must be taken to avoid spoofing.

To prevent spoofing, the identity authentication mechanism must be standardized. The 50G PON system needs to implement these mechanisms, and the activation of these mechanisms must be dynamically controlled by the operator, including but not limited to:

- Authenticates the ONU serial number and/or registration ID used for ONU registration.
- Client (CPE) authentication based on IEEE 802.1x.
- Needs a powerful identity authentication mechanism.

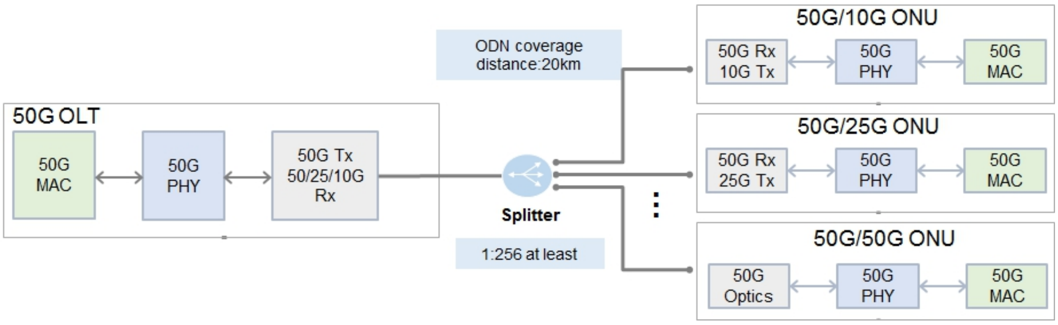
When the energy saving function is used, a low complexity but secure identity authentication method is also required to recover from the “sleep” mode.

To prevent data from being detected at the ONU, all downstream unicast data should be encrypted by using a powerful algorithm with good features, for example, Advanced Encryption Standard (AES). 50G PON should also provide a reliable key exchange mechanism necessary for encrypted communication. The 50G PON system must support uplink encryption and related key exchange, as well as the method of uplink encryption control during operation.

3 Key 50G PON Technology Analysis

Single-wavelength 50G PON is located in the Central Office (CO) of the access network. It uplinks the service network and downlinks users through various ONU user interfaces. Single-wavelength 50G PON supports a point-to-multipoint topology as well as video, data and voice services. Like GPON and 10G PON, single-wavelength 50G PON uses wavelength division multiplexing to implement single-fiber bidirectional transmission, and uses TDM for downstream traffic and TDMA for upstream traffic to implement point-to-multipoint communication between the OLT and the ONUs.

Fig. 3-1 Single-Wavelength 50G PON System Architecture



3.1 Wavelength Selection

The PON system has been developed for several generations, and different wavelengths are adopted in different standards. The wavelength resources of optical access networks are increasingly limited. In addition, the optical access networks are oriented to the vast number of users with diverse requirements, resulting in the coexistence of multiple PON generations in the existing networks. At present, only a small section of O band is available for 50G PON, which is not sufficient for the 50G PON systems.

In addition, after the rate is increased to 50G PON, a high-sensitivity receiver needs to be implemented so that the deployed ODN network can be reused. The front-end amplifier is an effective solution to improve the receiver sensitivity. However, the amplifier has out-of-band ASE noises, which affects the receiver performance. Therefore, an optical filter needs to be added and the wavelength of the filter needs to match that of the transmitter. To avoid using adjustable filters, the transmitter wavelength needs to be narrowed to a certain range. Therefore, 50G PON needs a wavelength scheme with narrow wavelengths. The specific wavelength selection scheme is still being discussed. Fig. 3-2 and Table 3-1 show the determined wavelength selection scheme of 50G PON.

Fig. 3-2 50G PON Wavelength Planning

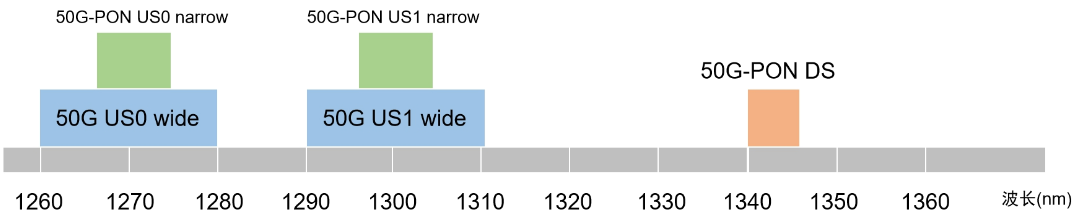


Table 3-1 50G PON Wavelength Scheme

Item	US0-wide 1260-1280nm	US1-wide 1290-1310nm	US0-narrow 1268-1272nm	US1-narrow 1298-1302nm
10G uplink	Determined	Determined	Under discussion	Under discussion
25G uplink	Determined	Determined	Under discussion	Determined
50G uplink	Not discussed	Not discussed	Under discussion	Under discussion

Considering that GPON has been deployed on a large scale in the existing networks and is migrating to 10G PON, it is expected that the coexistence of GPON, 10G PON, and 50G PON will be required in some scenarios. Therefore, ITU-T is also discussing the coexistence of the three wavelengths. It is preliminarily predicted that the range of the third wavelength is between 1280 nm and 1290 nm.

3.2 Line Coding

In the initial discussion of ITU-T, several line codes such as PAM4, duobinary and NRZ were considered. Because the PON system requires a very high power budget, ITU-T finally selects the NRZ code with the best receiving performance.

3.3 Line Rate Selection

ITU-T has clarified the requirement for 50G PON rate, and supports the combination of symmetric and asymmetric rates. The supported rate include 49.7664 Gbps downlink, as well as 9.95328 Gbps, 12.4416 Gbps, 24.8832 Gbps and 49.7664 Gbps uplink. There are little difference between 9.95328 Gbps and 12.4416 Gbps. It is estimated that three types of rates will be used: 12.4416 Gbps, 24.8832 Gbps and 49.7664 Gbps.

3.4 FEC Correction Technology

When the rate of the 50G PON line is increased, the receiver sensitivity will decline. It is necessary to improve the transceiver performance to reuse the ODN network that has been deployed in large numbers. To lower the requirement for high-speed optical component indexes, 50G PON introduces low-density parity check (LDPC) (17280, 14592) to implement FEC forward error correction by referring to IEEE NG-EPON. The encoding efficiency is about 84.84%. Compared with 10G PON RS (255, 221) coding, the BER before correction can be reduced to 10-2, and the receiving sensitivity can be increased by about 2 dB.

The LDPC algorithm is divided into hard value input and soft value input based on the decision method of the output data. Hard-value data is a 01-bit sequence after equalization decision, and is sent to the LDPC decoder to be decoded. The soft value input is the raw data that has not been decided, and the log-likelihood ratio (LLR) of the input signal, thus improving the error correction performance. Soft value input needs to be followed by the equalizer, and the ADC needs to perform digital sampling of original signals.

3.5 Common TC Technology

50G PON supports the PON-MFH (Mobile Fronthaul) application scenario, that is, PON-based 5G mobile Fronthaul. In this scenario, the OLT and the ONU provide service transmission between CU and DU, and 50G PON is required to support low latency. 50G PON implements low latency mainly through the following technologies: dedicated activation wavelength (DAW), coordinated DBA (Co-DBA), and allocation period reduction.

- Dedicated activation wavelength: The dedicated activation wavelength can be a newly defined wavelength or the wavelength of the PON system deployed before 50G PON, such as 10G PON wavelength and GPON wavelength. The dedicated activation wavelength may be an independent upstream wavelength. Under this condition, the dedicated active wavelength and the 50G PON downstream wavelength complete the activation process, including ONU discovery and ONU ranging. The ranging result on the 50G PON upstream and downstream wavelength is obtained through calculation. The dedicated activation wavelength can also be a pair of uplink/downlink wavelengths. Under this condition, the dedicated activation wavelength alone completes the activation process, including ONU discovery and ONU ranging. The ranging result on the 50G PON upstream and downstream wavelength is obtained through calculation. The dedicated wavelength activation technology avoids opening the quiet window on the 50G PON uplink wavelength, and successfully cancels the delay caused by the quiet window.
- Coordinated DBA (Co-DBA): The OLT learns about the upstream service transmission requirement of the ONU through the upstream device CU, and allocates the bandwidth to the ONU in advance, so that the service data can be cached as little time as possible in the ONU.
- Allocation period reduction: Reduces the time interval for the ONU to obtain the bandwidth allocation, thus reducing the service data cache time in the ONU. Each T-CONT can be allocated up to 16 times in the 125us period, that is, up to 16 burst can be sent in the 125us period.

To achieve ultra-50Gbps rate transmission, the channel binding technology of multiple channels can be used.

In channel binding, service data packets on the sending side are divided into several data units. For each data unit, the data packets are sent in the earliest channel among multiple channels. If there are multiple earliest channels, the data packets are sent in the channel with the smallest number. This rule is used until all data units are sent. On the receiving side, one data unit is received on the earliest channel among multiple channels. If multiple channels have the earliest receiving time, the channel with the smallest channel number is selected. After all data units are received in accordance with this rule, each data unit is assembled into service data packets in accordance with the receiving sequence.

In addition, due to different wavelengths, data units have different transmission delays on different channels. The sequence of data units transmitted on multiple channels on the receiving side may be different from that on the transmission side. Therefore, the data unit sequence recovery technology is required. Currently, the specific technology has not been determined in the standard. One possible technology is to send PSBd synchronously on each channel in the downlink direction and set a unified time reference point. The sending and receiving sequence of the data unit is based on this reference point and the upstream direction is similar. The other possible technology is that the sender determines the relative position of the data unit sent by each channel and marks this relative position in the data frame, and the receiver restores the data unit sequence according to these relative position relations.

3.6 50G PON PHY Layer Component

The PHY-layer component is one of the key technical problems that need to be solved in the PON system. The optical transceiver component that meets the performance requirements of the PON system is the core PHY component. With the increase of PON rate, in order to avoid introducing excessive dispersion cost in C band and avoid conflict with such system wavelengths as GPON, XG(S)-PON and TWDM-PON, uplink and downlink wavelengths are defined in the O band with low dispersion coefficient in the ITU-T G.9804 single-wavelength 50G PON standard.

The 50G PON PHY layer components mainly include optical transmission components, optical receiving components, Laser diode driver (LDD), burst TIA and clock recovery chip CDR (where, the upstream receiving direction requires burst clock recovery BCDR) and other key photoelectric components. The OLT optical transmission module can adopt EML and integrated SOA EML components. The OLT optical receiving component can adopt APD and integrated SOA PIN. The ONU is similar to the OLT. Unlike the OLT, the ONU driver needs to support the burst function, and the receiving does not need burst-mode clock data recovery (BCDR). The ONU optical transmission component with the upstream rate of 25 Gbps/10 Gbps can also use DML.

At present, the core photoelectric components in the industry are not mature yet. The optical component solutions, the indexes, standards, requirements, and the standards are still being discussed. There is no photoelectric component on the PHY layer applicable to 50G PON OLTs and ONUs. The experimental and simulation results of mainstream manufacturers in the industry indicate that 50G PON using the 50G EML transmitter and the 25G APD receiver is expected to obtain a single-wavelength rate of 50 Gbps. Although 50G EML optical components are available in the industry, they are mainly used for Ethernet 400GE optical modules with low transmit optical power (chip-level output optical power: 4-5dBm) and low extinction (>4 dB). The indexes need to be further improved if there are used for 50G PON. The 1342nm downlink 50G EML is absent. The 25G APD industrial chain is basically mature, and has been commercially used in optical modules such as Ethernet 50G ER and 100G/200G ER4 optical modules. Only a few manufacturers can provide a small batch of 50G APD samples. In terms of key electrical components, LDD and downlink receiving continuous TIA can reuse the data communication product components in the industrial chain. However, the LDD of the uplink burst laser driver lacks dedicated chips, and the uplink burst TIA component and burst clock recovery chip do not have available components.

3.7 Comparison of 50G PON and 10G PON Technologies

Table 3-2 Key Technologies of 50G PON and 10G PON

Item	50G PON	10G PON
Line rate (DS)	49.7664 Gbps	9.95328 Gbps
Line rate (US)	9.95328 Gbps, 12.4416 Gbps, 24.8832 Gbps, 49.7664 Gbps	2.48832, 9.95328 Gbps
Line coding	NRZ	NRZ
FEC	LDPC (17280,14592)	RS (248,216)
Quiet window	Open on DAW	Only open on working wavelengths
CO-DBA	Support	Not support
Maximum burst frame per T-CONT per 125us	16	4

Item	50G PON	10G PON
Coexistence of the same ODN	Coexist with 10G PON	Coexist with GPON
Channel binding	Supports TC-layer channel binding	Service-layer channel binding
Slicing	Support	Not support

3.8 Further Research Directions of 50G PON

At present, some technical contents of 50G PON have been determined, and some contents and directions have yet to be further researched and determined. The following two directions may be the focus of follow-up attention:

- The PON network will support the exclusive bandwidth requirement of multiple operators or services in the future. Its support for hard slicing is an important feature, which will support the establishment of rigid pipes for PON downlink scheduling, and will affect the existing PON protocol framework. If 50G PON supports this feature, how to be compatible with deployed networks such as XG(S)-PON needs to be discussed further.
- In order to meet the coexistence of optical modules with different the rate of 10 Gbps, 25 Gbps, and 50 Gbps, the uplink optical power budget of 50G PON is relatively tight. The problems including latency and the contradiction between performance and cost caused by the introduction of LDPC to improve the error correction capability needs to solved.

4 50G PON Application Scenario Analysis

The future broadband service development of operators is complicated and uncertain, and network capabilities will still be the most basic and determined core competitiveness and source of values of operators. Based on business development, market competition, technology evolution and other factors, the introduction of new technologies should not only take into account the demand for continuous bandwidth improvement, but also take into account the overall business support capabilities such as the support for XR/Metaverse, H-DICT, IoT, To B, and other services, the compatibility and integration requirements of existing networks, and the life cycle and ROI of equipment upgrade.

50G PON provides five times bandwidth of 10G PON, and adopts corresponding measures to optimize latency and jitter. Compared with 10G PON, 50G PON suits more scenarios and can provide the real 10 Gbps access capability. 50G PON can better meet the requirements for multi-service and full-scenario integration, PON dedicated line, POL private network, and 5G indoor coverage in the future, and realize the "convergence and unification" of IEEE 10G-EPON and ITU-T XG(S)-PON in the 50G PON era.

4.1 Home Ultra-broadband Access

50G PON mainly provides the high-speed Internet access, video and voice services to the home customers when it is applied in the home broadband access scenario. In order to meet the ever-increasing fixed network bandwidth requirements, especially 4K/8K, AR and Cloud VR, the typical bandwidth requirement is 1-10 Gbps per home, the access network needs larger bandwidth, and the PON technology needs to evolve continuously.

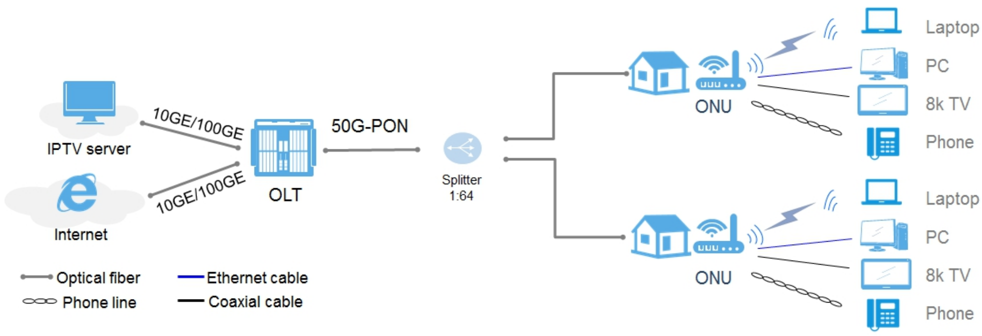
4.1.1 Gigabit Home Ultra-broadband Access

Table 4-1 Bandwidth Requirements of Different VR Video

VR Video	Time of Commercialization	Panoramic Bandwidth	FOV Bandwidth	RTT Latency	Packet Loss Ratio
Entry	-2 years	120M	48M	20ms	2.4×10^{-5}
Experience	3-5 years	630M	155M	20ms	1×10^{-6}
Extreme	6-10 years	4.4G	1.1G	10ms	1×10^{-6}

Fig. 4-1 takes Gigabit to home as an example to analyze the user bandwidth convergence ratio of the 10G PON and 50G PON port. As can be seen, 50G PON can provide a larger convergence ratio, a larger bandwidth channel, lossless compression and extreme user experience to users.

Fig. 4-1 Gigabit to Home Deployment Diagram



10G PON: 10G/64 (split ratio)/1G=1:6

50G PON: 50G/64 (split ratio)/1G=1:1

Considering an actual installation of 50% and a concurrent rate of 70%, the actual downlink bandwidth requirement of 64 subscribers is 64*50%*70%*1G=22G. The calculation proves that 50G PON can meet the requirements of higher installation rate and concurrent rate.

In addition, the high bandwidth and low latency requirements of home broadband services depend on the high throughput and low latency requirements of 8K HD video, AR, and Cloud VR services.

With reference to China Telecom's white paper on low latency optical network technology, and according to the formula in Fig. 4-2, TCP throughput is limited by three factors: bandwidth, RTT, and the packet loss rate ρ. Suppose that the bandwidth is sufficient, and the packet loss rate is not considered due to good network quality, latency becomes the decisive factor. If the latency is too large, the users' bandwidth experience cannot be improved. In this case, the problem cannot be solved by only improving the bandwidth, this phenomenon is called "bandwidth black hole."

Fig. 4-2 Throughput Formula

$$\text{Throughput} \le \min\left(BW, \frac{CWND}{RTT}, \frac{MSS}{RTT} \times \frac{1}{\sqrt{\rho}}\right)$$

Suppose the bandwidth (BW) is 10 Gbps and the unidirectional delay is 10 ms (the round trip time RTT is 20 ms). According to the above formula, the maximum throughput of the TCP protocol is only 26.3 Mbps, much lower than the network bandwidth. The industry generally believes that the throughput of real-time large-throughput services such as 4K/8K HD video should be 1.5 times of the actual code stream rate to ensure service quality. As a result, the 4K HD video requires a throughput of 30-45 Mbps, and the maximum RTT is 12-17 ms according to the above formula.

VR requires a user bandwidth of more than 1G, and a lower delay of 5 ms (RTT delay) to improve user experience.

Table 4-2 Requirements of VR Services for Bandwidth and Latency

Standard		Pre-VR	Entry-Level VR	Advanced VR	Ultimate VR
Video definition		3840*1920	7680*3840	11520*5760	23040*11520
Strong interactive VR service	Code rate	18 Mbps	60 Mbps (3D)	390 Mbps	680 Mbps
	Bandwidth requirement	50 Mbps	200 Mbps (3D)	1.40 Gbps	3.36 Gbps
	RTT	10 ms	10 ms	5 ms	5 ms
	Packet loss ratio	1.00E-6	1.00E-6	1.00E-6	1.00E-6

With reference to the above bandwidth and latency requirements, 50G PON can effectively improve the bandwidth for the 4K/8K service of the home broadband HD TV, and uses the low latency technology to reduce the latency performance of the access equipment, thus reducing the RTT of the entire network, and finally improving the throughput of the video service and user experience. In addition, if the forwarding delay of the 50G PON system is less than 1 ms, the stringent service requirements of Cloud VR can be basically met.

4.1.2 10 Gigabit Home Ultra-broadband Access

With the maturity of the 50G PON industry chain and the decrease of costs, 10 Gigabit home network construction becomes possible. In common home applications, various Network Attached Storage (NAS) is used as a home storage center to replace the local hard disk. In addition, the NAS is used together with the home cloud to enhance the use of large files and video sharing within homes, and expand the home network from single-point coverage to mesh coverage, which is in urgent need of 10 Gigabit broadband.

At present, the 10 Gigabit home intranet can be deployed in two mainstream modes. One mode is to connect the home NAS, PC and other devices to form a 10 Gigabit intranet through the Category 6 cable (CAT 6) and 10 Gigabit switch. The other is the FTTR whole-home fiber coverage solution, where all devices are directly connected by fiber and communicate at a rate of 10 Gigabit.

After the 10 Gigabit network is deployed, the egress broadband interface becomes a new bottleneck. Based on it, 50G PON, as a new PON access technology, can provide up to 50 Gbps bandwidth for the egress of the home intranet, fully supporting full range of 10 Gigabit applications and providing symmetric uplink and downlink network ingress and egress.

4.2 Deterministic Campus Network

Information and communication technologies are integrated and penetrated into various industries, and digital transformation and upgrade of industries are accelerating. Industrial networks oriented to industrial users such as factories, ports, campus, and hospitals have different requirements for network transmission, and have higher requirements for network determinacy such as coverage, delay, bandwidth, security, and reliability.

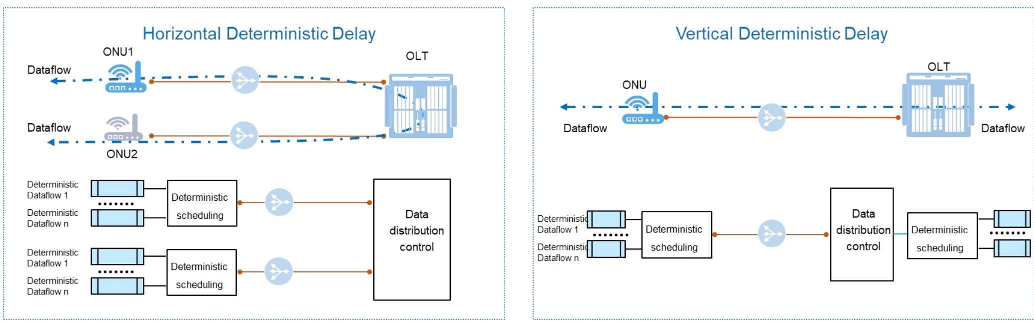
Deterministic transport provides guaranteed delivery with low delay, low delay variation (jitter), and extremely low loss operates over the end-to-end network. Deterministic transport often expects extreme values), its main target is to guarantee the upper limit of these parameters.

Key parameters of the deterministic network include deterministic delay, deterministic bandwidth and deterministic packet loss. More parameters about deterministic network include periodic critical control data streams, maximum end-to-end delay, high availability etc, which are highly relevant to industrial Internet.

The communication modes of industrial production networks mainly include deterministic periodic communication, deterministic aperiodic communication, non-deterministic communication, and hybrid mode. Except for non-deterministic communication, the other three communication modes have strict requirements for the delay and jitter of instructions. If instructions cannot be delivered or executed within a deterministic time, the product yield and production efficiency may be reduced.

The deterministic PON network uses timestamps and a fixed delay scheduling mechanism to implement end-to-end deterministic PON delay, ultra-low jitter, and zero packet loss. For the eastbound to westbound network transmission between two ONUs, as shown in the figure below: Firstly, deterministic services are identified at the ingress of the PON network device, i.e. the ingress of the ONU user interface, and marked with a timestamp. Secondly, the system calculates the time that the service packets are transmitted at the egress of the ONU user interface according to the fixed transmission time requirement of deterministic services between two ONUs in the PON network. Finally, the system schedules packets and sends service packets in strict accordance with the calculated time to ensure that the incoming and outgoing time of deterministic service packets is constant. For the southbound to northbound network transmission between an ONU and an OLT: Firstly, the deterministic service is identified at the ingress of the PON network device. i.e. at the ingress of the ONU user interface or the OLT uplink interface, and marked with a timestamp. Secondly, the system calculates the time that the service packets are transmitted at the egress of the OLT uplink interface or the ONU user interface in accordance with the fixed transmission time requirement between the ONU and the OLT uplink interface in the PON network. Finally, the system schedules packets and sends service packets in strict accordance with the calculated time to ensure that the incoming and outgoing time of deterministic service packets is constant.

Fig. 4-3 Gigabit to Home Deployment



The deterministic PON network based on the service flow timestamp and fixed delay scheduling mechanism can ensure the deterministic delay, zero jitter, or nanosecond-level low jitter, and zero packet loss during service transmission in the PON network, meeting the strict communication quality and precision requirements of industrial production networks.

4.2.1 Remote Medical Treatment

With the development of medical robots, doctors and nurses are expected to cooperate with professional medical robots in different areas to complete the operation process. The operation instructions are sent to the operation desk through the forward link of the network, and the HD images and signals on the operation site are sent to the remote medical staff through the backward link. The instructions issued by different medical personnel shall be delivered to the on-site robots in real time, cannot be delivered too early or too late (requiring low jitter). In this remote surgery scenario, to ensure the smooth completion of the operation, the end-to-end communication delay between the patient and the doctor must be less than 50ms, and the jitter must be less than 200 μs.

4.2.2 Electric Power Grid Relay Protection

A relay protection device is placed at each end of the power cable to send equal amount of current to the peer end over the network, and the local current is compared with the current received from the peer end. If the difference between the two currents is smaller than the limit, it indicates that the line is not faulty. Otherwise, it indicates that a fault occurs on the line. Since there is no time synchronization between the relay protection devices at both ends, it is necessary to use the time of RTT/2 to measure the unidirectional delay, and make operations according to the delay.

To ensure the accuracy of the relay protection system, the unidirectional delay between two directions should be less than 200ms and the jitter should be less than 50 μs. Nowadays, the relay protect devices are transported over wireless or wireline telecomm devices, so it will be a stringent requirement on low delay and jitter for the transport network.

4.2.3 Underground Mine Communication

Underground mine communication problems include:

- Signal coverage: Low anti-interference, weak penetration, and small scale coverage of wireless signals shall be considered.
- Signal transmission stability: Large number of operation terminals, complicated environments, transmission cables, and reliability.

The all-optical network built upon 50G PON can be extended to all terminals in the mine to provide stable signal transmission. The types of terminals include sensor information collection, video monitoring, personnel communication, and remote control.

Deterministic requirements of underground mine communication:

- Bandwidth: 30 M-100Mbps
- Delay: 30 ms-100 ms

4.2.4 Smart Industrial Manufacturing

The smart manufacturing scenario imposes strict requirements upon network transmission delay, security and reliability in the data collection, industrial control, automation and man-machine interaction scenarios. The communication guarantee should reach the millisecond-level end-to-end delay and near 100% reliability.

The limitations of the traditional industrial network make it difficult to meet the requirements of various scenarios. Industrial networks used to be industrial buses, and then evolved into industrial Ethernet networks. However, they still have problems such as high costs, long deployment time, inconvenient deployment or unavailable deployment, poor network interoperability, and difficult troubleshooting, which cannot meet the high flexibility requirements of future customization for production lines.

Traditional narrowband industrial networks cannot support high-density access of industrial terminals as well as high concurrency and large data traffic. Even if some campus are switched to industrial Ethernet equipment, the maximum uplink bandwidth is generally no more than 10 Gbps, and the maximum uplink bandwidth of super-large campus usually do not exceed 40 Gbps. The next-generation 50G PON technology can provide a larger access bandwidth than the 40 Gbps network, with obvious advantages in terms of bandwidth.

The industrial PON equipment is located in a workshop-level network in the industrial

Internet architecture. Optical networks are connected to the equipment layer through the industrial-level access gateway (ONU) equipment. The ODN implements the integration of industrial equipment data and production data to form the industrial POL solution. Finally, the connection between the convergence gateway (OLT) and the enterprise IT network enables integrated networking of enterprises as well as reliable and effective transmission of industrial data.

Deterministic indexes include the parameters such as delay and jitter. In particular, jitter requirements are very important to industrial control networks. Industrial Ethernet switches can realize 1us. The deterministic delay depends on the service requirements, for example, the typical target requirement is 1 ms+/-20us. The next-generation 50G PON technology supports deterministic forwarding technologies such as TSN and DetNet to ensure reliable and deterministic forwarding of industrial data on the industrial campus.

4.3 Enterprise Ultra-Broadband Access

50G PON can provide 10 Gbps symmetric access rates to meet the requirements of enterprise dedicated lines and all-fiber networking inside the enterprise. In addition, 50G PON can be combined with the new FTTR-Business (such as all fiber at SME,) mode to implement the evolution from one fiber to one network inside the enterprise.

4.4 FTTM

50G PON has a great application potential in future fixed-mobile convergence (FMC) applications. At present, 5G is being deployed on a large scale, but the overall investments in mobile infrastructure construction are slowing down. Therefore, the construction and planning of 5G networks are crucial.

According to the statistics, 85% of the 5G network traffic is generated indoors, and 40% of the user complaints is about network coverage, among which 70% is about indoor coverage. 5G network coverage and quality can be greatly improved if the indoor 5G coverage problem is solved.

The current indoor coverage solution IPRAN adopts a point-to-point connection mode, and the low connection efficiency causes extremely high costs in a 5G indoor coverage scenario. In addition, the capacity of the general indoor pipelines may not support the deployment of large quantities of point-to-point optical fibers, therefore it is not ideal in the indoor coverage scenario.

In addition, 10G PON for mobile backhaul has been widely used in the 4G networks in the Indonesian market, and has achieved good results. However, due to the bandwidth and standards limitations, the 10G PON technology cannot meet the requirements of 5G backhaul for high bandwidth, low latency, and low jitter.

Table 4-3 Bandwidth and Latency Requirements of 5G Backhaul

Item		Requirement	50G PON
50G PON Backhaul	Bandwidth	Peak: 3-20 Gbps	Satisfy, 50 Gbps
	Latency	eMBB: 2 ms	Satisfy, 200 μs
	Clock synchronization	Class A (± 50 ns) Class C (±10 ns) CoMP: G.8273.2	Satisfy, ns level jitter

In general, 5G small cells used in indoor coverage can provide a downlink bandwidth of 700 Mbps and an uplink bandwidth of 50 Mbps. When 50G PON is used for backhauling 5G small cells, and a single PON port generally supports a split ratio of 1: 64, a single PON port can support 64 5G small cells, and one 50G PON line card with four ports can support 256 5G small cells, fully meeting the indoor coverage requirements of common buildings.

In addition, FTTM is not only for home users, but also for commercial buildings with abundant FTTH fiber resources, helping operators save a large number of backhaul fiber network resources and laying a foundation for FMC applications in the future.

5 ZTE 50G PON Development

As a technology leader in the fixed network field, ZTE has been committed to making contributions to the development of PON technologies, and has been cooperating with the industry to advance the PON technologies.

In March 2022, ZTE launched the industry's first precision 50G PON prototype at MWC Barcelona 2022, featuring precision bandwidth (a fivefold increase in bandwidth and 2M-10Gbps tunable bandwidth), precision latency (2.5 ms @10 km-> 200 μs @10 km), and precision jitter (ms-level->ns-level).

In May 2022, ZTE unveiled the industry's first ONU prototype in support of 50G PON and Wi-Fi 7 at the FTTH Council at MWC Barcelona 2022. It achieves a maximum theoretical rate of 19 Gbps, and accesses the devices four times more than that of Wi-Fi 6, meeting the requirements for high bandwidth and multi-terminal access in the future home and government&enterprise scenarios.

In October 2022, ZTE released the 50G PON&10G PON Combo solution at Network X.

ZTE has submitted more than 60 proposals to standards organizations including ITU-T.

6 Summary

After years of development and commercial applications, the fiber-based PON technology with passive and point-to-multipoint features has been highly recognized in the industry and achieved success due to its comparative advantages over twisted pair/coaxial cables. The PON technology is developing in three directions:

- Application field expansion
  - All-optical access: FTTH is a traditional field of PON. It is being upgraded from GPON to 10G PON to provide gigabit bandwidth to the home.
  - All-optical home: Evolves from gigabit to home to gigabit at home. All-optical home networks are built upon optical fibers, allowing each room to deploy high-frequency and high-bandwidth Wi-Fi 6 wireless access.
  - All-optical campus: The POL technology replaces traditional Ethernet switches to build all-optical campus networks, and implements fiber-to-conference room, fiber-to-camera, fiber-to-office desk, and fiber-to-machine connections.
- Bandwidth quality improvement

GPON has been put into commercial use for more than 10 years. The FTTH network is being upgraded from GPON to 10G PON, with quadrupled bandwidth. It is beyond doubt that 50G PON, which provides a bandwidth five times faster than 10G PON, is the next-generation PON technology of 10G PON.

People’s living habits are changing greatly under new situations. Online education at home and high-quality home-based office services have become a must, which propose higher quality guarantee requirements for FTTH networks and all-fiber home networks. The expanded applications of all-optical campus have higher requirements for network quality, ensuring the high efficiency of production and office activities on campus.

- AI network

No matter FTTH, all-optical home networks in thousands of homes, and all-optical campus networks that support the production activities of the campus, artificial intelligence is an important means to improve network quality.

  - AI network operation and maintenance: automatically warns, locates, and recovers faults.
  - AI-based network optimization: automatically improves network service assurance.

The contents of 50G PON being researched include a bandwidth five times faster than 10G PON, determinacy, and measurement of endogenous AI. The introduction of these new technologies and features will bring about a qualitative leap to 50G PON, and meet the requirements of the three development directions of the PON technology as mentioned above.