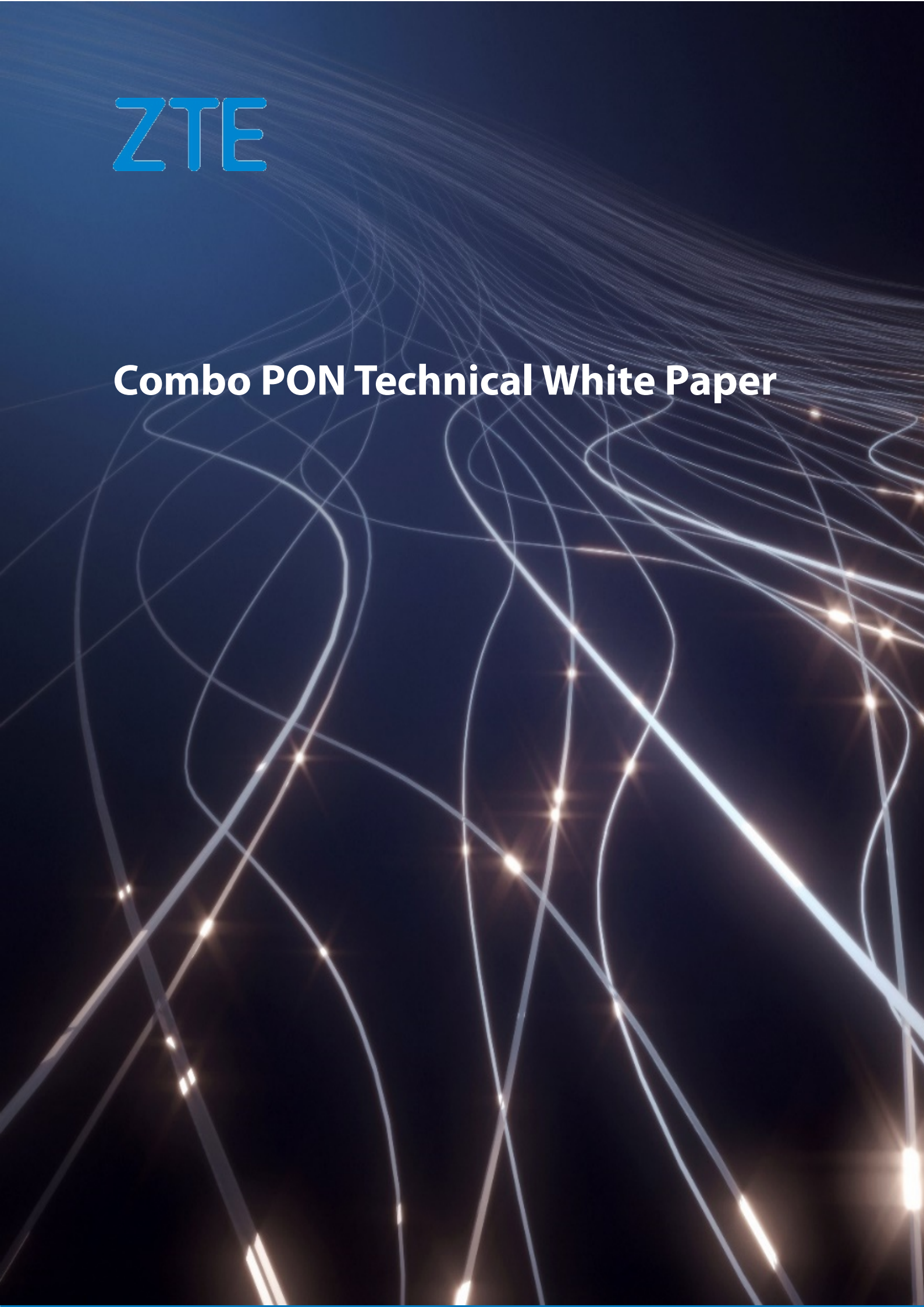

Combo PON Technical White Paper

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1 Origin of Combo PON

1.1 Source of the Combo Concept

As the most excellent transmission medium, optical fiber with a P2MP architecture is the basis for the tremendous success of PON over the past decade. Currently, the EPON and GPON technologies have been put into large-scale commercial use to provide upstream and downstream 1G-level access bandwidth. With the rapid development of the traffic-hungry video services such as 4K/8K and AR/VR, the users' demand for bandwidth is increasing rapidly, and the optical access network enters a period of large-scale 10G PON construction. However, the smooth network evolution needs to address the requirements of reusing the existing ODN and the forward compatibility of legacy ONUs, which puts forward higher requirements for the PON technologies.

Therefore, the Combo PON concept is introduced for the coexistence and evolution from GPON to 10G-GPON. The Combo concept has been well-established, and has been widely used in the integrated service access network MSAN. It combines POTS services and DSL services over the same Combo line card to facilitate cabling and engineering applications. At the same time, the Combo concept has been fully considered during the evolution from EPON to 10G-EPON. For example, the 10G-EPON standard released by IEEE in 2009 has fully considered the forward compatibility of EPON and the requirements of ODN reuse. The 10G-EPON port is compatible with the simultaneous access of EPON ONUs and 10G-EPON ONUs, thus achieving smooth upgrade of ONUs as per demand, and effectively protecting the operators' early investments.

1.2 Combo PON Meets the Requirement for the Evolution From GPON to 10G-GPON

GPON has attracted wide attention in the industry due to its unique performance advantages including higher bandwidth utilization, more user access and transmission of multiple services, as well as carrier-class network monitoring and service management. Therefore, with the increasing maturity of the industry chain, GPON has gradually become a mainstream optical access technology and has been deployed on a large scale

in China. Meanwhile, in order to meet end users' increasing bandwidth demands, ITU-T released the 10G-GPON standard.

ITU-T also considers the forward compatibility of GPON in the formulation of the 10G PON standard. However, due to the insufficient consideration on product application design in the early stage, the GPON and 10G-GPON industry chains develop independently. No matter XG-PON line cards or XGS-PON line cards are used, GPON ONUs and 10G-GPON ONUs cannot coexist in the same ODN. When the line cards are replaced, the ONUs connected to the line cards must be replaced and upgraded at the same time, which cannot meet end users' requirements for on-demand upgrade, and increases the operators' initial investment pressure.

In the early stage that GPON coexists with 10G-GPON and starts to migrate to 10G-GPON, some operators use the external WDM1r multiplexer solution for smooth bandwidth evolution. However, this solution has the disadvantages of large equipment room footprint, optical power loss incurred by the multiplexing, and complicated cabling. To further address the above challenges, ZTE proposed the innovative Combo PON concept that integrates GPON and 10G-GPON ports into one, and GPON, 10G-GPON and WDM1r optical modules into one, supports smooth migration from GPON to 10G-GPON, and accelerates the bandwidth from 100 Mbps to 1000 Mbps. Highly applauded among operators due to its excellent compatibility and convenience in actual project deployment, Combo PON technology has become the mainstream solution for 10G-GPON construction, and has been put into large-scale commercial use.

2 Technical Values of Combo PON

2.1 Fiber Broadband Develops Towards Multi-Service Access

- **Home Broadband Services Are Diversified**

Broadband services have witnessed rapid development in recent years. Home service applications have gradually changed from voice, Internet, multimedia web pages, and standard-definition videos to diversified high-definition videos, home entertainment, online office/education, and living services. Users have higher requirements for service experience, such as immersive, multi-view video experience as well as efficient and

smooth online office/education experience, which all contribute to the growing demand for the access network bandwidth from 100 Mbps to 300 Mbps, 500 Mbps and 1000 Mbps. Considering the service development, market competition and network evolution, some operators promote the upgrade from GPON to 10G-GPON and take initiative in the market.

In the future, with the development of broadband access technologies, people's demands for family life quality will increase continuously, and home broadband services and applications will become extensive. With the gradual informatization of family life and diversified home service requirements, such as smart home, Augmented Reality (AR), Ultimate High Definition (16K), and even holographic interaction, new services are emerging, bringing better service experience to people, and raising increasingly higher requirements for the interconnection between home broadband networks and equipment in homes.

- **Fixed Broadband Services Expand to Enterprises**

With the continuous improvement of global information levels, many countries are undergoing transformation from traditional economy to digital economy, and technologies such as broadband access, service cloudification, big data, Internet of Things (IoT), and artificial intelligence (AI) have been developed greatly. With the digital economy boom, the support capability of broadband networks is increasingly prominent, and broadband has become an indispensable strategic infrastructure to promote the national informationalization and people's living standard, and further promote sustainable economic development.

The broadband service development is based on home access, and gradually penetrated into high-value vertical industries to improve broadband network efficiency and to shorten the investment period. At present, fiber broadband access has been gradually expanded from home scenarios to safe city, safe village, smart community and high-speed enterprise Internet access scenarios, followed immediately by the enterprise cloud desktop, enterprise access to cloud, and the education industry such as Cloud VR followed immediately, and are being explored and practiced by telemedicine and intelligent manufacturing due to the involvement of more precise control.

- **Fixed Broadband Allows for the Access of 5G Base Stations at a Low Cost**

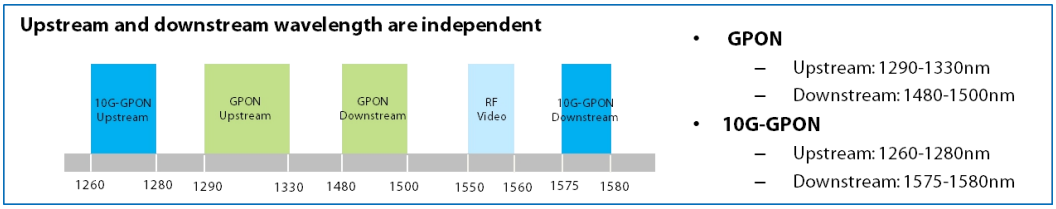
With the issuance of 5G commercial licenses all over the world, 5G applications will boom. Compared with 4G, the number of 5G base stations in densely populated urban areas will

be multiplied, and the demand for fiber access resources will also increase dramatically. The already deployed high-density coverage ODN networks can connect 5G base stations at a low cost, as per demand, and conveniently. Compared with the solution that fibers are directly connected to 5G base stations, the P2MP-based ODN connecting 5G base stations can greatly save feeder fibers and reduce access costs, suitable for rapid 5G coverage in densely populated urban areas.

2.2 Smooth Evolution to 10G-GPON

10G-GPON and GPON upstream and downstream wavelengths are independent of each other from the perspective of the standards. 10G-GPON does not have an innate basis for the coexistence with GPON.

Fig. 2-1 GPON and 10G-GPON Upstream and Downstream Wavelengths



The current GPON network cannot be upgraded to the 10G-GPON network in a very short period of time. It needs to be upgraded step by step according to various factors such as service development, different user needs, regional economy and investment value. This requires that 10G-GPON is deployed at the central office first, and then migrate the CPE side as per demand, which meets the high-bandwidth access requirements of high-value users and the requirements of step-by-step upgrade.

At the same time, considering the construction cost and maintenance difficulty, it is impossible to deploy and maintain 10G-GPON and GPON networks at the same time, especially reconstructing the ODN is costly, long and complex. When the two types of optical access systems coexist, user service development and upgrade are not flexible.

In view of it, ODN reuse and compatibility between two generations of ONUs need to be solved to upgrade the existing GPON network to the 10G-GPON network.

2.3 Low-Cost Speed Acceleration and Construction

In the areas where the GPON network has been widely deployed, how to upgrade the GPON network to the 10G-GPON network at a low cost to meet the increasing demands of value-added broadband services is the biggest pressure facing the operators at present.

Besides the cost of 10G-GPON system equipment at the office end and ODN construction and transformation, upgrading the ONUs of the entire network requires huge investments and a long return period because 10G-GPON ONUs currently cost more than GPON ONUs, and the number of ONUs is huge. The Combo PON solution allows for the simultaneous connection of existing GPON ONUs and the on-demand upgraded 10G-GPON ONUs by upgrading the OLTs on the system end of the optical access network without the need of changing the existing ODN, which meets the requirements of high-value users, helps operators quickly balance investment and revenue, and builds 10G-GPON networks with a light asset.

In the initial stage, GPON ONUs are deployed at the user side. Later, the ONUs in the user's home are upgraded to 10G-GPON ONUs according to the bandwidth upgrade requirements and service development of home users, so as to avoid the high cost of directly using 10G-GPON ONUs. Model calculation shows that 50% of the initial PON equipment investment cost can be saved by doing so. ** (The model includes 30% of real installation rate, 90% of GPON service, and 10% of 10G-GPON gigabit service in a new scenario).

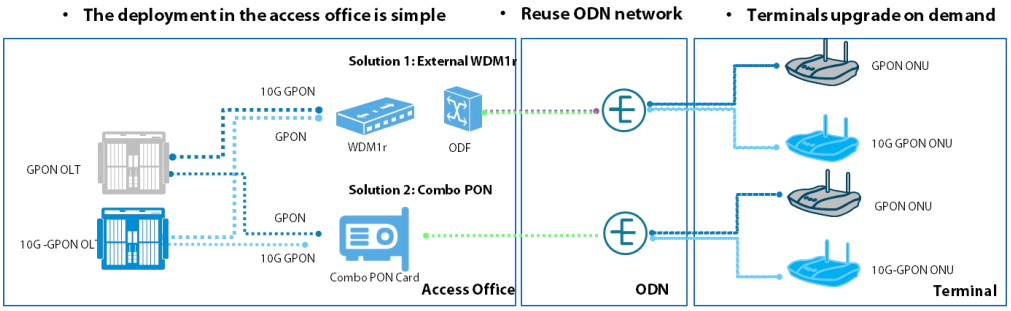
2.4 Comparison of the Combo PON Solution and the External WDM1r Solution

At present, there are two solutions for upgrading the existing GPON network to the 10G-GPON network:

External WDM1r solution: Add external WDM1r multiplexers in the ODN to reuse the existing OLT GPON ports and the newly added 10G-GPON ports, so as to reuse the ODN. The GPON and 10G-GPON ONUs continue to use their respective network to access the service.

Innovative Combo PON solution: Uses Combo PON cards to replace the existing GPON cards at the OLT side. The Combo PON ports provide the three-in-one functions including GPON, 10G-GPON, and multiplexer to reuse the ODN and connect the GPON and 10G-GPON ONUs. The existing GPON cards can be allocated to the areas with low bandwidth requirements.

Fig. 2-2 Comparison of the External WDM1r Solution and the Combo PON Solution



The external WDM1r solution needs to interrupt the existing PON lines and services. External WDM1r multiplexers are added to the optical power budget to decouple the WDM1r from the equipment. The WDM1r can be deployed independently and managed in a centralized manner. However, due to the high requirements for the existing access network equipment room conditions and construction, high construction difficulty, and long construction period, the external WDM1r solution has seldom been used in actual deployment.

- The external WDM1r multiplexer needs to be installed on the racks of the access network equipment room with limited space.
- The increase of additional 1-1.5 db optical power loss may cause insufficient link optical power budget.
- ODF optical fiber routes need to be re-planned.

Compared with the external WDM1r solution, using the Combo PON solution can greatly reduce engineering difficulty, facilitate construction and guarantee rapid deployment. It is a preferred deployment solution to upgrade GPON to 10G-GPON:

- “Zero” increase in equipment room space: Centralized installation is implemented without considering the installation of an external optical multiplexer.
- "Zero" increase in optical power insertion loss: It is unnecessary to consider the

insertion loss caused by the external optical multiplexer and adjust the optical power budget of the line. It has no influence on the optical link of the existing GPON network.

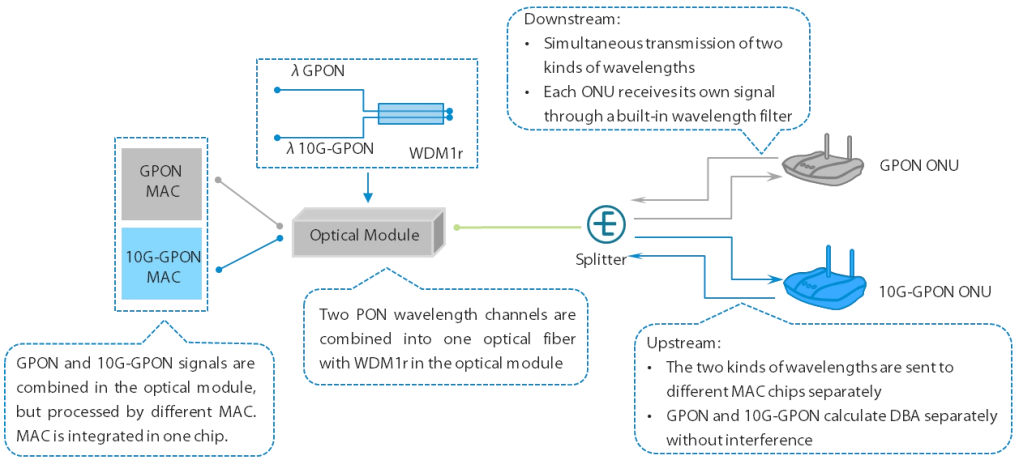
- "Zero" change in ODN: At the central office OLT side, the tail fibers of the existing GPON are connected to the Combo PON ports. After the data cutover, the network upgrade is completed. The feeder fibers, splitters and branch fibers do not need to be adjusted.
- No change in service flow: Except for new data in the resource system, service provisioning and ONU provisioning remain unchanged.
- It only needs the 10G-GPON service management data, and has no influence on the existing GPON services.

3 Key Combo PON Technology Analysis

3.1 Basic Principles of Combo PON

A single Combo PON port is an integrated port of 10G-GPON and GPON that uses one fiber link. There are two internal physical channels (the external multiplexer is built in the optical module) inside the Combo PON port. Fig. 3-1 shows the operating principle of Combo PON.

Fig. 3-1 Combo PON Technical Principle Diagram



In the downstream direction, the GPON and 10G-GPON channels are processed by separate MAC addresses respectively, the data is sent to the optical module for WDM1r multiplexing, and then sent to the optical fiber for transmission. The GPON and 10G-GPON wavelengths are transmitted over the ODN at the same time. When the optical signals reach the ONUs, 10G-GPON ONUs only receive the 10G-GPON signals, and GPON ONUs only receive the GPON signals.

In the upstream direction, GPON ONUs and 10G-GPON ONUs use different wavelengths for signal transmission. After the GPON and 10G-GPON optical signals reach the PON optical module on the OLT, they are demultiplexed inside the optical module and then sent to different MAC channels for processing.

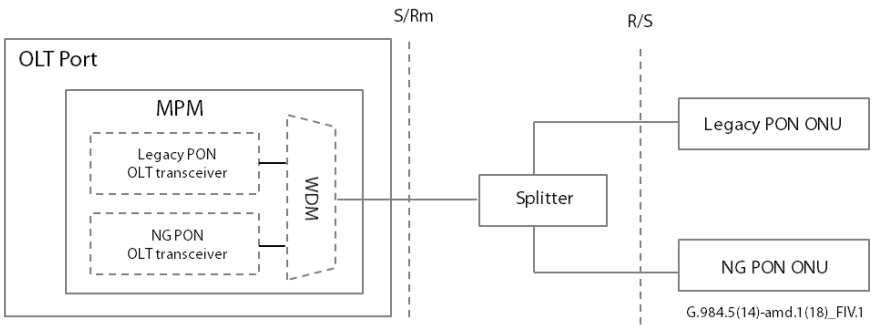
The innovation and breakthrough of key Combo PON technology mainly includes two aspects: SFP+ small form factor 3-in-1 Combo PON optical module and high-density GPON&10G-GPON PON MAC integrated chip.

3.2 3-in-1 Optical Module

G.984.5 Amendment 2 Appendix IV defines this 3-in-1 Combo PON optical module as the MPM module. CCSA has also standardized the Combo PON optical module, including technical requirements, test methods, reliability tests, electromagnetic compatibility tests, inspection rules, labels, packaging, transportation and storage requirements.

Fig. 3-2 shows the MPM architecture.

Fig. 3-2 MPM Architecture Reference Diagram



The MPM optical module supports both the traditional GPON and 10G-GPON. Because the two PON systems share the same ODN, to ensure that the GPON system provides sufficient optical power budget in the traditional ODN network, the 10G-GPON should

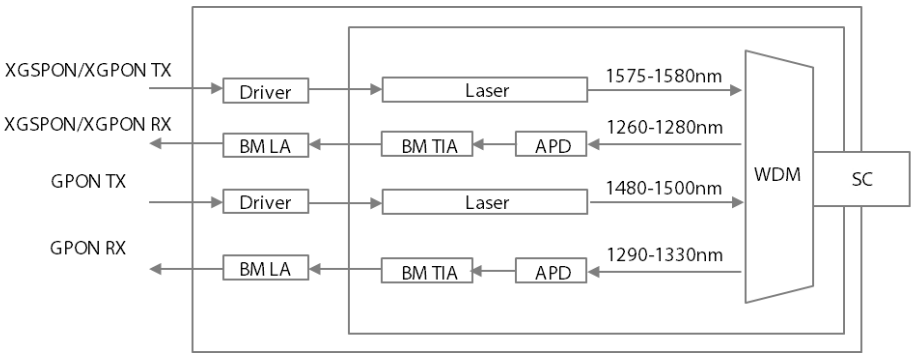
provide sufficient link budget to cover the traditional ODN. The WDM1r will incur additional optical power loss. For the ODN network with insufficient optical power budget, the introduction of WDM1r may affect the original GPON services. Therefore G.984.5 Amendment 2 Appendix IV defines the PMD parameters of the MPM module at point S/Rm (after WDM1r), so that the optical power budget of the GPON service in the ODN network is consistent with that in the legacy network. At the same time, Appendix IV adjusts the PMD parameters of 10G-GPON, so that the optical power budget of the 10G-GPON service in the ODN network is consistent with that of the GPON service. The types of optical modules defined by MPM include Class B+, Class C+, and Class D.

Table 3-1 Types of Optical Modules Defined by MPM

OPL class	**B+**	**C+**	D
Minimum loss	13 DB	17dB	20dB
Maximum loss	28 DB	32dB	35dB
NOTE – Optical path loss classes B+, C+ and D are generally applicable for GPON and 10G-GPON MPM from the S/Rm point.			

The Combo PON optical module integrates the GPON optical module, 10G-GPON optical module and WDM1r. The footprint of the GPON and 10G-GPON optical modules is compressed, and the built-in WDM1r will also incur additional optical power loss. Thus, making the optical power index of the Combo PON SFP + small form factor optical module reach the requirement of MPM Class C+ becomes one of the technical difficulties. Fig. 3-3 shows the detailed operating principle of the integrated optical module. It is necessary to increase the transmit power inside the optical module and improve the receiver sensitivity to compensate for the attenuation caused by WDM1r, so that the GPON and 10G-GPON channels at the egress of the optical module can still meet the GPON and 10G-GPON optical module parameter requirements defined in the standards, and avoid the impact of the Combo PON upgrade on the legacy user services. ZTE has launched SFP+ high-density 16-line Combo PON line cards, with the same density as the industry's highest density 16-line GPON line cards. This allows the operators to replace the GPON line cards with the same port density to implement smooth upgrade from GPON to 10G-GPON.

Fig. 3-3 Schematic Diagram of Combo PON Optical Module

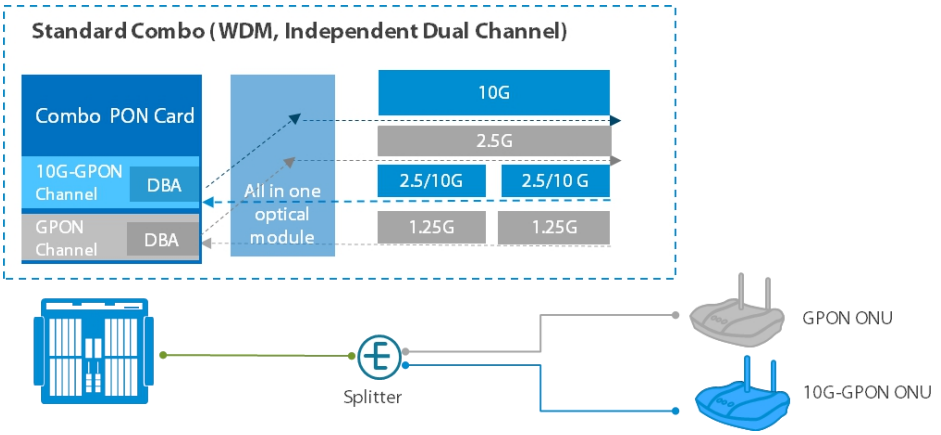


3.3 2-in-1 MAC Compatibility Design

The high density and large capacity of the access products require a single PON card to provide 16 PON ports, and a single PON MAC chip to simultaneously support 16 GPON and 10G-GPON channels. The Combo PON card can be used to one-to-one replace the 16-port GPON line cards that account for a considerable proportion of operators' deployment, making engineering implementation more economical and convenient. Through integration, the OLT can meet the core competitiveness requirements of low power consumption and low cost. ZTE has developed the in-house multi-mode PON MAC chips with industry's highest port density, and in support of multiple working modes.

When the chip works in the Combo PON mode as shown in Fig. 3-4, GPON and 10G-GPON MAC are two independent channels.

Fig. 3-4 Technical Principle Diagram of Standard Combo (WDM, Independent Dual Channel)



The implementation of ZTE Combo PON has the following features:

- Independent dual channels of GPON and 10G-GPON.
- The GPON channel and the 10G-GPON channel comply with the GPON standard and the 10G-GPON standard respectively.
- GPON and 10G-GPON provide independent bandwidth and independent DBA scheduling in the upstream and downstream.

3.4 Comparison of WDM Combo PON and TDM Combo PON

In addition to the WDM Combo PON mentioned above, another type of Combo PON is implemented in the upstream through TDM of the GPON channel and the 10G-GPON channel, as shown in Fig. 3-5. This is also a built-in multiplexing solution, which uses the same upstream and downstream wavelengths as well as downstream implementation mode as the WDM solution. The difference lies in the upstream bandwidth capability and upstream DBA bandwidth allocation mode. 10G-GPON and GPON share the same receiving channel in the upstream, and the upstream bandwidths of 10 Gbps/2.5 Gbps and 1.25 Gbps are scheduled in a unified DBA mode.

Fig. 3-5 Technical Principle Diagram of Standard Combo (TDM, Shared Channel)

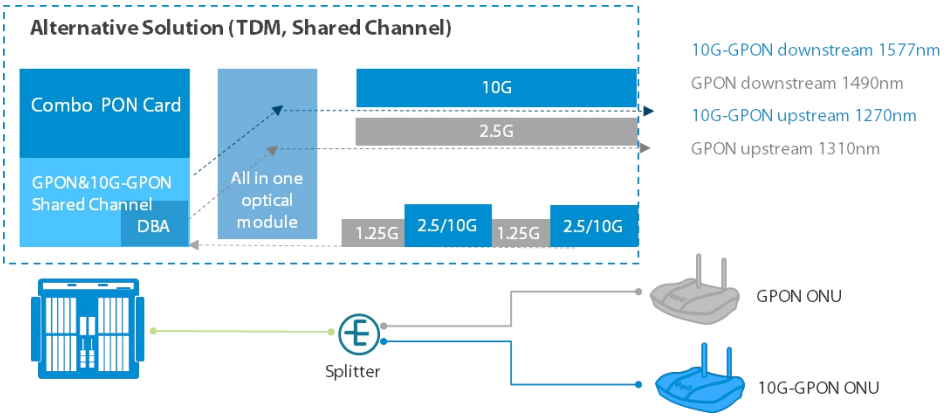


Table 3-2 Comparison Between WDM Combo PON and TDM Combo PON

Item	WDM Combo PON	TDM Combo PON
Standards Compliance	In WDM Combo PON, the GPON channel complies with G.984 series, and the	TDM Combo PON has many modifications and private

Item	WDM Combo PON	TDM Combo PON
	10G-GPON channel complies with G.9807 series standards. The technologies, chips and components are fully standardized.	implementation to the original international standard.
Uplink Bandwidth Capability	Dual channels receive signals independently. Dual DBA. Services are not affected by concurrency. The upstream bandwidth efficiency is high. The upstream bandwidth is the sum of the upstream bandwidths of 10G-GPON and GPON channels.	The OLT needs unified DBA to coordinate the upstream bandwidth of GPON ONUs and 10G-GPON ONUs. In addition, GPON and 10G-GPON use TDM in the upstream, only one type of ONUs can transmit data at a certain time, leading to the deterioration of upstream bandwidth capability and allocation efficiency.
Industry chain support	The WDM Combo PON solution has obvious technical and performance advantages and is more in line with the customer interests. It has been widely recognized by the industry and put into large-scale commercial use. At present, all of the mainstream optical module manufacturers in the industry have the capability of large-scale supply of WDM optical modules.	The TDM solution uses non-standard private implementation at the cost of performance deterioration, and has not been put into large-scale commercial use.

4 Global Applications of Combo PON

At present, more than 40 operators worldwide have carried out 10G-GPON deployment and upgrade to meet the requirements of the gigabit user markets.

In the Chinese market, with the implementation of the "Broadband China" strategy and the deepening of the "Speed-Up and Cost-Reduction" plan, Gigabit network coverage has become one of development objectives of China's “14th Five-Year Plan”. China Telecom, China Mobile, and China Unicom have all taken gigabit speed-up as a strategic objective, and optical broadband access development has entered the Gigabit era.

Combo PON is the mainstream large-scale commercial deployment solution for the

upgrade of GPON to 10G-GPON. By the end of 2020, more than 3 million Combo PON ports had deployed in existing networks.

5 Future Evolution and Prospect of Combo PON

It is widely believed in the industry that networks will evolve towards ultra-high bandwidth, ultra-low latency, and massive connection. How to simply and efficiently upgrade system capacity and reduce transmission latency has become a hot research topic in the PON arena. The next-generation Combo PON technologies following 10G PON will develop in two directions: one is to increase the single-wavelength rate to meet the deployment requirements of future wired broadband, and the other is to use multi-wavelength superposition to meet the deployment requirements such as future 5G fronthaul.

Single-wavelength rate increase: At present, the 10G PON fixed access network has entered the batch deployment phase. With the increasing popularity of home broadband access and government & enterprise access requirements, 50G PON will be the next deployment trend of optical access. To meet the networking requirements of different services, 10G PON and 50G PON will coexist for a long time. It is a proven effective solution that the central office equipment adopts the optical transceiver module in support of the coexistence of multiple modes, therefore the Combo PON of 10G PON and 50G PON will become an important evolution direction in the post 10G PON era. This solution can effectively save deployment space in equipment rooms and reduce the power consumption of optical access devices. By using the ODN resources of the existing network, this solution reduces the operators' network construction costs and meets the end users' requirements for on-demand upgrade.

Multi-wavelength superposition: With the acceleration of 5G deployment process, how to use the existing FTTx network resources to develop 5G networks at a lower cost and in a short period of time, and accelerate the distribution of 5G services has become a noteworthy direction. The independent multi-wavelength superposition technology can achieve logical point-to-point transmission, ensure network security isolation while effectively reducing the transmission delay of the legacy PON network, and meet the technical requirements such as 5G fronthaul. Based on the independent wavelength superposition mechanism, one optical fiber can support the simultaneous access of FTTx and 5G fronthaul. This direction can make full use of the existing extensive FTTx network

infrastructures, such as optical fibers, pipelines, curb cabinets and access equipment rooms, to rapidly construct 5G networks at a lower cost, improve the FTTH network resource utilization, and provide stable and reliable dual-gigabit access to users through the resource sharing of fixed networks and mobile networks,