Evolution of Optical Access Networks

1 Evolution Requirements

1.1 Challenges Brought by an Era of 10X Bandwidth for Broadband Network Operators

According to an Informa report, global Internet traffic increases 7-fold every five years, which conforms to the Moore’s Law, while bandwidth per subscriber climbs by a factor of 10 every five to six years, which complies with the Nielsen’s Law. In the future, services will become increasingly bandwidth-intensive; this in turn will spur the exponential growth of bandwidth.

The number of broadband subscribers in the world also steadily rises. A 2012 survey by Point Topic shows that the global broadband subscriber base recorded an average quarterly growth of over 2% from Q3 2011 to Q3 2012. Ovum forecasts that the worldwide number of broadband subscribers will surpass 800 million by 2015.
To address the urgent needs for more bandwidth presented by service development, two standardization bodies formulated respective 10G PON standards: the IEEE released IEEE802.3av in 2009 and the ITU-T/FSAN launched G.984 in 2010. The industry is aware that, to accommodate long-term service development, broadband technology must move beyond 10G PON. A post-10G PON era featuring large capacity and higher bandwidth is set to arrive. To prepare for this era, the industry initiated research and standardization on NG-PON2. The IEEE focuses on the technology path of increasing single-channel rates to 40GE/100GE, while the ITU-T/FSAN takes the path of using multi-wavelength-channel multiplexing. Both paths aim to improve network bandwidth and system capacity. In April 2012, the FSAN designated TWDM-PON, which uses four-wavelength-channel multiplexing, as the main technology direction of NG-PON2. TWDM-PON is not a brand-new replacement technology. Rather, it represents a new network construction mode and is a PON system architecture for multi-wavelength overlapping built on the existing 10G TDM PON foundation. The FASN is also mulling the PtP WDM mode, which allows multiple PtP channels to be transmitted through WDM over one fiber. PtP WDM and TDM channels coexist in the same ODN via wavelength multiplexing. Figure 3 shows the system architecture of multi-wavelength PON as stated in the NG-PON2 standard ITU-T G.989.2:
1.2 Paving the Way for 5G with High-Bandwidth Wired/Wireless Convergence

In the 5G era, the total transmission capacity required by the digitalization of RF signals sent by large-scale antenna arrays is expected to reach terabit levels. If the current technology is used to transmit the wireless signals, the cost will be very high. To address the problem, wired and wireless network resources need to be integrated to achieve efficient transmission and maximize yields. This is a hot topic of research as well as the most important part of NG-PON2 application. The trend is to build on the existing wired networks and employ new low-cost fiber/wireless integrated transmission technology to replace conventional wireless transmission. Digital units such as remote ADCs/DACs are stripped off and move upwards to the baseband pool which is housed in the cloud room. Wireless signals are carried via fiber through multi-domain multiplexing technologies such as WDM and TDM. Mobile services are directly extended to all the areas originally covered by wired services. High-frequency wireless access is first provided within a small scope and then extended via low-cost fiber to expand the coverage area. This mechanism both eliminates the shortcomings of wireless high-frequency coverage and takes full advantages of the flexibility of wireless technology. Figure 4 shows how this application works:
WDM mode:
The TWDM PON wavelengths specified in NG-PON2 are not used. An external, independent PtP WDM module used specially for wavelength transmission is employed to transmit signals between BBU and RRU. The ODN of the optical access system is reused to save on backbone fiber. If WDM PtP uses CWDM wavelengths, cheap CWDM modules currently available can be used. Each wavelength channel can deliver up to 10 Gbps bandwidth.

TDM mode:
Transmission is conducted through TWDM PON wavelengths, and OLT needs to process wireless signals.
Since neither mode has been standardized, they are a focus of discussion for standards organizations.

![WDM Technology Figure](image)

Figure 4 Wired/Wireless Converged Application

2 Building Sustainable Networks by Flexibly Increasing Bandwidth and Capacity

Smoothly upgrading an optical access network involves not only flexibly improving network bandwidth and system capacity but also complying with the existing network. For operators, inheriting the already deployed ODN and equipment means no ODN reconstruction and rewiring is needed for the upgrade. This saves labor costs and other investments and ensures the sustainability of the original network plan. NG-PON2, which applies to the post-10G PON era, uses wavelength multiplexing to enable the coexistence of the upgraded and original optical access networks. As user demands increase, wavelengths can be stacked to provide higher bandwidth and larger capacity. An optical access network can be smoothly upgraded to NG-PON2 in three modes:

2.1 External WDM Mode

The OLT is configured with PON cards of different technology standards. When the network needs to be upgraded, the system uses cards of the new standard. Multi-channel signal light generated are multiplexed/demultiplexed by an external passive WDM
component before being converged to the ODN for transmission. See Figure 5 for an illustration of the mechanism. The inherent insertion loss of the external WDM component raises the power budget of the original ODN.

Figure External WDM Mode

2.2 OLT-Side Card Replacement Mode

The OLT is configured with a multi-channel card, with each channel working on a fixed PON standard. Different channels have optical modules of corresponding PON standards. Multi-channel signal light generated are multiplexed/demultiplexed by a built-in passive WDM component before being outputted through the single optical interface of the card to the ODN for transmission. In a network upgrade, just one card is needed to replace all the existing cards of different standards, as shown in Figure 6. The inherent insertion loss of the built-in WDM component is offset among the multi-channel card by technical means and thus does not raise the power budget of the original ODN.

Figure 6 OLT-Side Card Replacement Mode

2.3 SDO Mode

The OLT is configured with a multi-channel card working on variable standards. Each channel can be set through software to different PON standards. Different channels have optical modules of corresponding PON standards. Multi-channel signal light generated are multiplexed/demultiplexed by a built-in passive WDM component before being outputted
through the single optical interface of the card to the ODN for transmission. In a network upgrade, just one card is needed to replace all the existing cards of different standards, as shown in Figure 7. The operator can configure bandwidth through software according to user needs.

![Figure 7 SDO Mode](image)

**3 Key Technological Issues of NG-PON2**

Designated by the ITU-T/FSAN as the main technology direction of NG-PON2, TWDM-PON uses a PON system architecture with multi-wavelength overlapping built on the existing XG-PON1 foundation. Wavelength multiplexing is a key feature differentiating TWDM-PON from XG-PON1.

### 3.1 Key Technology of Highly Integrated OLT Optical Modules

In a TWDM-PON system, multiple 10G optical transceiver modules are stacked and connected through an external passive optical multiplexer/demultiplexer. Such an encapsulated module is big in size and results in low integration at the OLT side. The industry generally favors using hybrid integration technology based on silicon photonics to replace the traditional discrete component assembly. The new technology can effectively reduce encapsulation size and increase optical module integration at the OLT side.

Compared with the traditional assembly encapsulation mode for optical modules, the photoelectric hybrid encapsulation technique at the integrated chip level based on silicon photonics is vastly different. Improving the silicon photonics-based hybrid encapsulation technique by referencing the mature encapsulation technique of large-scale integrated circuits is a key technology critical to the industrialization of highly integrated OLT optical modules.
3.2 Key Technology of Colorless ONUs

In the TWDM-PON system, adjustable transceiver technology is designated as the only solution for colorless ONUs. Traditional transceiver components have already been put into mature commercial use. However, high costs make it impossible to apply traditional transceiver components in access networks. Adjustable transceiver technology needs a new solution to bring its costs down to a level that enables application in access networks.

There are major differences between the adjustable transceiver technology used in TWDM-PON and that used in traditional scenarios. Adjustable transceiver technology for TWDM-PON faces a number of technical hurdles:

a) Wavelength shift in burst mode

Traditionally GPON and XG-PON use a single-wavelength mechanism. By contrast, TWDM-PON contains a multi-wavelength burst transmission scheme and the wavelength interval is just 100 GHz. The wavelength shift caused by burst transmission has a severe impact on adjacent channels. The problem is particularly acute for 10 G applications.

b) How to balance low cost and wavelength stability

Access networks require low costs, which means that adjustable transceiver components must change their encapsulation mode from a traditionally complicated form to a small size. However, with the temperature control of small-size encapsulation, how to ensure wavelength accuracy at 100 GHz for adjustable transceiver components remains a challenge.

c) Channel crosstalk caused by the PON architecture

Different from a transport network, the multi-channel signals of a TWDM-PON ONU are multiplexed by an optical splitter and the signals transmitted by a tunable laser cannot be effectively isolated from each other. This generates crosstalk between adjacent channels and affects signal quality. Currently no effective solution is available in the industry to address this problem.

4 Conclusion

In the development of optical access networks, application requirements need to be well matched with the industrialization of key technologies. The research progress of the key technologies of NG-PON2 is different from their industrialization. As a result, the formal commercialization of TWDM-PON will not start until 2018, and PtP WDM will first be deployed.

Every upgrade of optical access networks aims to address the core requirements of the time. 10G PON meets application needs both currently and in five years.

Requirements and technologies both develop gradually instead of suddenly. 10G PON forms an essential foundation of NG-PON2 and is a stage that cannot be bypassed.
Therefore, the evolution direction of optical access networks is from 1G PON to 10G PON to NG-PON2.