Next Generation Optical Access Networks: A Review

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ABSTRACT
Passive Optical Networks (PONs) represent one of the most attractive access network solutions. As the demand for higher bandwidth per user is increasing and accelerating, there is an inevitable need for an evolution from the currently deployed passive optical networks (PONs) to next-generation optical access networks. Apart from meeting the bandwidth requirement, the Next Generation Access Networks must overcome the limitations of existing gigabit-class PONs i.e. low capacity, limited reach, and restricted mobility. Different architectures included in this paper for realizing the NG-OAN are based on different standards introduced by IEEE and ITU-T. A brief summary of future scope has also been included.

Keywords
PONs, FTTX, DSL, AON, AWG

1. INTRODUCTION
A part of telecommunication network which connects subscribers to their immediate service provider is called an access network. There is a strong competition between various types of access technologies in order to meet the needs of bandwidth hungry broadband services. The rapid growth in Internet demand and high bandwidth applications has led to a huge penetration into the optical access networks [1]. The prominent access technologies are digital subscriber loop (DSL), which is divided into two standards: asymmetric digital subscriber loop (ADSL), and very high speed digital subscriber loop (VDSL). Other standard is Hybrid fiber coax (HFC) that is the deployed current access technology which uses video distribution and the Internet for data transfer. Wireless fidelity (Wi-Fi) network based on IEEE 802.11 standard and Worldwide Interoperability for Microwave Access (WiMAX) network based on IEEE 802.16 standard form a part of wireless access deployment [2].

The fiber-to-the-x (FTTX) is the strongest competitor amongst all currently deployed access technologies. It offers a lot of benefits because of the small weight, small size and immunity to electromagnetic interference offered by a fiber making it a better substitute to copper in new generation networks. [3].

Bandwidth limitation of the last mile bottleneck access technologies and the increasing demand of high-bandwidth applications have motivated the introduction of fiber to the home (FTTH) to provide new high-speed services.

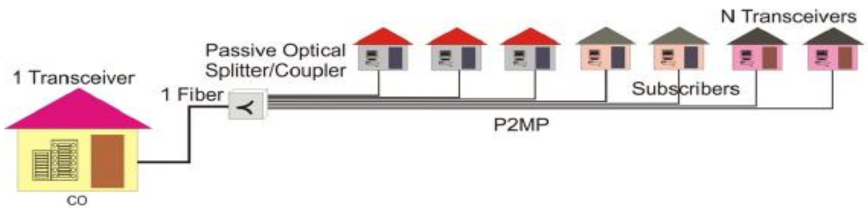

Fig 1: A typical FTTx access network

2. TYPES OF FTTX NETWORKS
Depending on whether there is a use of passive or active devices, we can classify FTTx networks as either Passive Optical Network (PON) or Active Optical Network (AON).

Active Optical Networks require some electrically powered equipment, such as Ethernet switch, router or multiplexer, whereas Passive Optical Networks require passive equipment, such as an optical splitter or arrayed waveguide grating (AWG) [4].

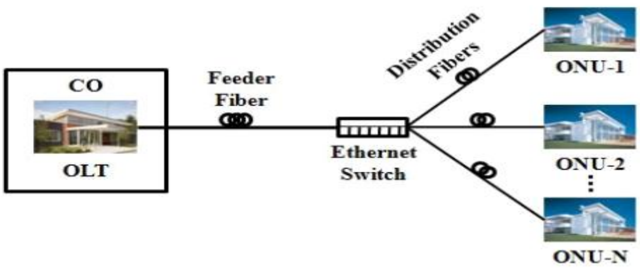

Fig 2: Active Optical Access Network

A passive optical network (PON) is one of the FTTH implementations that has become a good solution for access networks. PON uses a point-to-multipoint (P2MP) topology. It consists of an optical line terminal (OLT) at the service provider's central office (CO) and a number of optical network units (ONUs) near end user side. An optical fiber and splitter form an Optical Distribution Network (ODN) [5].

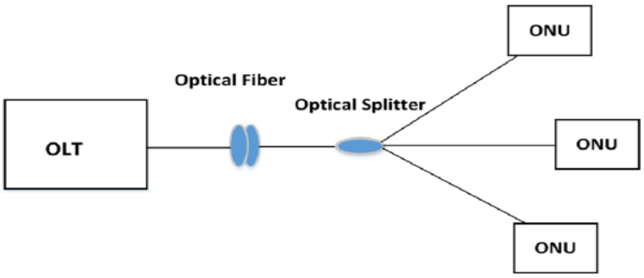

Fig 3: Passive optical access network

The amount of fiber and the central office equipment is reduced in PON as compared to point-to-point architectures. The signal leaving the OLT port reaches the power splitter and each output port gets a replica, of the original optical signal but with reduced power. The power splitter has an intrinsic splitter factor (1: N), which depends on the number of ONTs/ONUs we want to serve.

3. CURRENT GENERATION PON STANDARDS

3.1 B-PON (Broadband PON)

It is a TDM based multiplexing system, developed by FSAN called Broadband Passive Optical Network (BPON). It is based on Asynchronous Transfer Mode (ATM) and also referred as Asynchronous Transfer Mode Passive Optical Network (APON). The first BPON standard was published in 1998 in the ITU-T G.983 series recommendations [ITU09]. This standard specified the aggregate transmission rates for up to 622.08 Mbps in the downstream (DS), 155.52 Mbps in the upstream (US) [6].

3.2 EPON or GEPON (Ethernet or Gigabit Ethernet PON)

This standard is based on Ethernet protocol and was adopted by IEEE as a standard named 802.3ah. Its purpose is to implement Ethernet technology in the PON systems so to enhance the capabilities of the network with less number of components, very low operation & maintenance cost. The data broadcasted downstream from OLT to multiple ONUs in variable-length packets of up to 1,518 bytes, according to IEEE 802.3 protocol. It supports P2MP subscriber access network topology. EPON offers the aggregate symmetrical line rates of 1.25 Gbps in the DS and US [7].

3.3 G-PON (Gigabit PON):

Gigabit-capable Passive Optical Network (GPON) is ITU-T PON standard, developed by FSAN. It is defined in the ITU-T G.984 series recommendations [ITU09] first published in 2003. Aggregate GPON system transmission rates for up to 2.48832 Gbps in the downstream and upstream direction are specified in the standard. The transportation mechanism used in this referred to as GPON Encapsulation Method, (GEM) [8].

4. NEXT GENERATION OPTICAL ACCESS TECHNOLOGIES

TDM based PON systems which form current generation PON need to be upgraded to meet the increasing bandwidth demand. This has led to the proposal of the NG-PON by network groups- FSAN, IEEE and ITU. Requirements for NG-PON have been defined to meet the demands by 2020 as follows:

- It must be able to provide data rate of 128 Gb/s up to 500Gb/s.
- support from 256 up to 1024 ONUs (customers),
- 20–40 km of extended passive reach
- low capital and operational expenditures
- Co-existence with G-PON [2].

Two solutions proposed by the network operators to meet these demands are:

4.1 Mid Term next generation PON (NG -PON1)

10E-PON and XG-PONs are proposed as mid-term solutions to overcome the insufficient capacity of the current generation standards. These are the Time division multiplexing (TDM) based enhancements of E-PON and G-PON respectively. NG-PON1 aims to offer high bandwidth to support more users in the network. Despite the efforts that have been made by NG-PON1 in increasing the data rate to 10 Gb/s for the downstream and upstream in a symmetric manner, still there is a raising demand of higher data rates. So, the NG-PON1 based TDM-PON is still inadequate to accommodate new bandwidth hungry applications and is unable to satisfy the next-generation requirements because of many users sharing the same infrastructure i.e. radio resource during different time intervals.

4.2 Long Term Next Generation PON (NG-PON2)

The migration from currently deployed PON standard systems such as G-PON, G-EPON, and 10 G-PONs (NG-PON1), to Long term NGPON is aimed at supporting higher data rate than all other previously deployed standards apart from improving the economic investments made to deploy these legacy PON systems. The second stage of next-generation passive optical network (NG-PON2) is based on usage of two different multiplexing techniques i.e. TWDM-PON and WDM-PON.

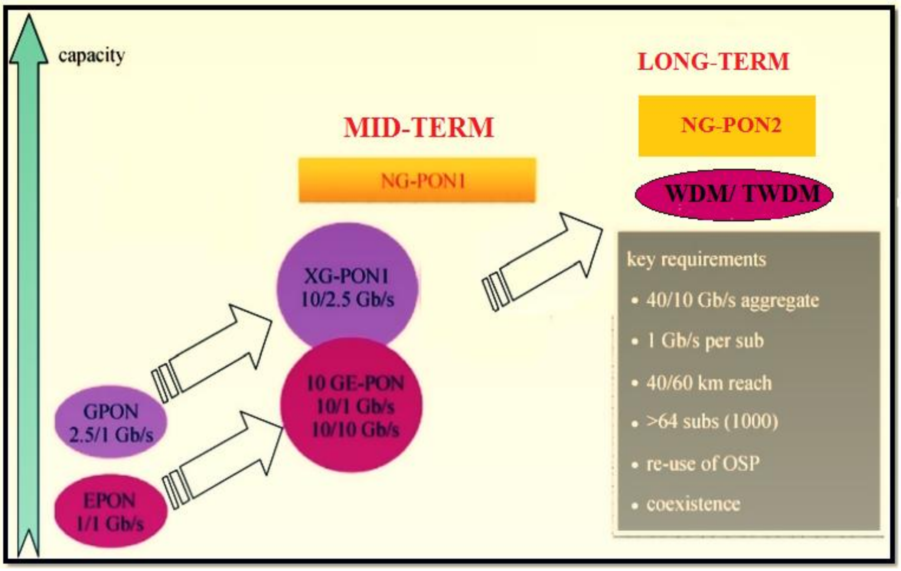

Fig 4: Migration scenario of PON

5. PON MULTIPLEXING TECHNIQUES

The different multiplexing techniques used in PON are:

5.1 Time Division Multiplexing PON (TDM -PON)

TDM-PON is the most common PON architecture that works on the time division multiplexing protocol. The whole bandwidth is available to all the users and they can transmit and receive their data as per assigned time slots. In the downstream direction, splitter broadcasts all the packets from the OLT towards each of ONU. These ONUs will recognize their own packets through the address labels embedded in the head of the packets.

Disadvantage of TDM-PON: A major roadblock for the future development of TDM-PON is provided by the shared traffic structure. Apart from this, the use of an optical power splitter leads to security issues and significant power losses as 1:32 optical splitter imposes more than 17 dB insertion loss.

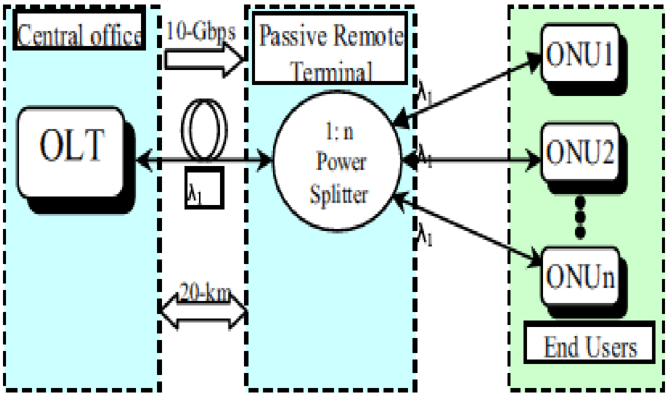

Fig 5: TDM -PON multiplexing architecture

5.2 Wavelength Division Multiplexing PON (WDM -PON)

In the future the rate of the traffic demand escalation is expected to be more. So, the improvement of the existing system is needed to meet the future requirements. The capacity of the networks can be enhanced by assigning the different wavelengths to the separate users who share a single fiber [2]. Because of this, WDM will remain a promising solution to fulfil the requirement of more bandwidth in the future. It also promises more security and lower power losses.

Signals of different users are coded on separate wavelength channels, and then routed to different ONUs by the (de-) multiplexer. Splitting of wavelength is done at passive wavelength multiplexer, e.g., AWG in the remote node. AWG offers reduced insertion loss i.e. 3-5 dB that helps to improve the power budget as well as increasing the transmission distance.

Point-to-point (PtP) link, in which a dedicated wavelength channel is reserved between the OLT and each ONU, enables each ONU to operate at the full bit rate of its own wavelength channel.

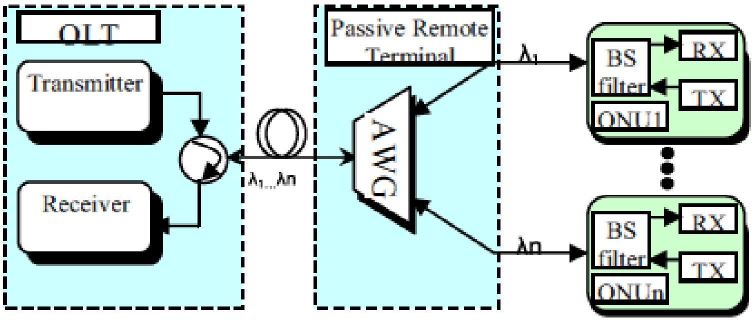

Fig 6: WDM-PON Multiplexing architecture

5.3 Hybrid WDM/TDM PON (HPON)

PON technique which combines WDM and TDM technologies is called HPON and is the most promising candidate for NGOA networks. Firstly, more numbers of wavelengths get assigned to the different groups of Optical Network Units (ONUs). Then each wavelength is further shared on time division basis by several ONUs of the same group using TDM technique. The entire wavelength is first divided into number of wavelengths using WDM technique. High split ratio per wavelength (large no. of users) is provided by TDM-PONs and large number of wavelengths and high capacity per wavelength offered by WDM- PONs.

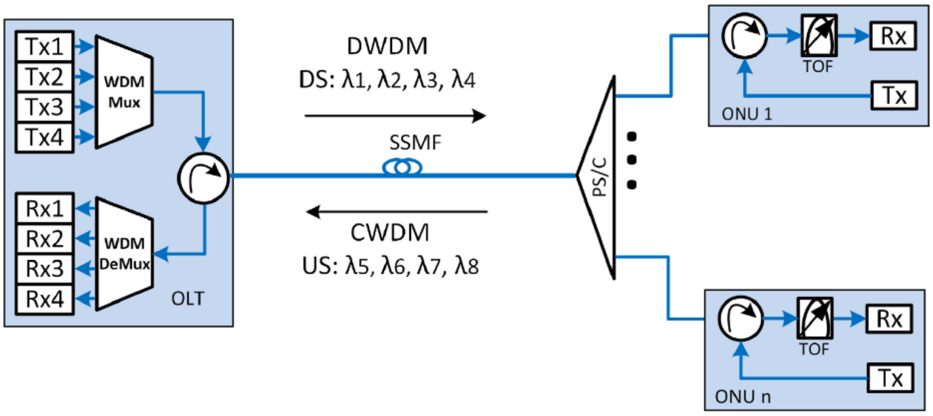

Fig 7: Hybrid PON Multiplexing architecture

6. FUTURE TRENDS

NG-PON2 is the technology of the future. In the coming future, access based on the PONs will be dominant. Since this technology is maturing fast, it could be an impetus to quicken the development of FTTH networks based on Hybrid PON. Although being in the laboratory phase in some countries, this technology may become available in the market in next couple of years to come. Still there is a lot to investigate in the following areas:

6.1 Colorless ONUs

Future research efforts are focused on to realize the 'colorless' ONU, i.e., a wavelength-independent ONU. Such an ONU must contain a tunable transmitter and receiver device. A tunable filter will be used to select or tune to any of the downstream wavelengths. For upstream wavelength, tunable laser will be used to provide colorless ONU to enable easier network laying and maintenance [9]. The schemes to realize these include injection locking, wavelength seeding, remote modulation, spectrum slicing and wavelength tuning.

6.2 Fiber Wireless networks (Fi-Wi)

Service operators are looking to integrate optical and wireless technologies, so to combine WTDM -PONs with emerging broadband wireless access technologies such as WiMAX, WiFi so to exploit their complementary features, i.e. high capacity provided by optical network and mobility offered by wireless network. A FiWi network can be either radio over fiber (RoF) technology or radio and fiber (R&F) technology. In RoF, signals are processed in a CO where an optical carrier is modulated by an RF signal before being sent over an optical fiber to a remote antenna unit (RAU) to be transmitted again over the air [10].

In R&F technology, wireless users can communicate directly through their medium rather than being transferred to the optical network.

6.3 Long Reach Optical Access (LROA)

The limitations of the existing PONs, such as their limited range and low splitting ratio will be overcome by a new technique called Long reach optical access. The LROA is based on the use of optical amplifiers that will extend the reach and also increase the splitting ratio. Moreover, it offers a cost-effective solution in which the end users can be connected directly to the core network rather than being switched through central offices. The number of central offices is consolidated into a trunk exchange by combining the access and metro segments of the telecommunication network into a backhaul segment [10].

7. CONCLUSION

Fiber based access networks can deliver performance that can support the increasing demands for high speed connections. The various requirements in the NGOA, such as the need to have a higher bit rate, extended reach, increased splitting ratios, and mobility, provided the researchers with the opportunity to propose different architectures. Although many of these proposed architectures are interesting from the technical perspective, the cost, bandwidth per user, and the number of accommodated subscribers remain the dominant factors for commercial success.

Currently, NG-PON2 has been the subject of intense research interest and the most promising candidate among NG-PON2 systems is the TWDM-PON system. TWDM-PON is selected by FSAN as the best candidate for NG-PON2 because it addresses the NG-PON2 requirements of bandwidth capacity higher than 40 Gbps, good backward compatibility, ability of supporting future customer applications and low upgrade cost. Colorless ONUs, Long reach access networks and Fi-Wi networks are some of the emerging areas of research in the fields of PONs.

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