Chapter 4
Wavelength Division Multiplexed Passive Optical Networks
Principles, Architectures and Technologies

Calvin C. K. Chan
The Chinese University of Hong Kong, Hong Kong

ABSTRACT
Wavelength division multiplexed passive optical network has emerged as a promising solution to support a robust and large-scale next generation optical access network. It offers high-capacity data delivery and flexible bandwidth provisioning to all subscribers, so as to meet the ever-increasing bandwidth requirements as well as the quality of service requirements of the next generation broadband access networks. The maturity and reduced cost of the WDM components available in the market are also among the major driving forces to enhance the feasibility and practicality of commercial deployment. In this chapter, the author will provide a comprehensive discussion on the basic principles and network architectures for WDM-PONs, as well as their various enabling technologies. Different feasible approaches to support the two-way transmission will be discussed. It is believed that WDM-PON is an attractive solution to realize fiber-to-the-home (FTTH) applications.

INTRODUCTION
Nowadays, access to the Internet has become an indispensable part of the daily lives in modern cities. Wide deployment of access network infrastructure has enabled the service providers to connect to all of the enterprise and residential users, thus the number of Internet users as well as the market of broadband access have experienced an explosive growth over the recent years. In addition to the conventional voice and broadcast video traffic, the current network is also carrying various real-time network services and interactive media-rich applications. Therefore, the demand of bandwidth in the current and next generation Internet is ever-increasing drastically. The current predominant broadband access technologies deployed, including digital subscriber line (DSL), and community antenna television (CATV), have their limitations in terms of bandwidth upgradeability, network scalability and robustness. As the
network services and applications are getting more data-centric and involve more real-time interactive communications among all parties, the next generation broadband access solutions should be flexible, scalable and robust enough to meet the high bandwidth requirement and assure good quality of service for the data traffic.

Passive optical network (PON) (Effenberger et al., 2007) is a promising solution to enable high-speed broadband access. It is based on fiber-optic technology which unleashes the enormous transmission bandwidth in the optical fiber. Therefore, it solves the bandwidth bottleneck of the current copper-based access solutions and provides higher bandwidth to meet the traffic demand in the access networks. APON is typically a point-to-multipoint optical network on which the optical line terminal (OLT) or the central office (CO) delivers services, via a long fiber feeder, to the remote node (RN), where the optical power is split and fed into multiple distribution fibers to reach many optical network units (ONUs) at the subscriber side. The infrastructure between the OLT and the ONUs does not require any electric power supply, thus can greatly ease the network management of the outside plant facilities. A single wavelength is employed at the OLT to carry the downstream traffic, mainly for service distribution, while a relatively lower bit rate upstream wavelength is also employed at the ONU to carry the requests from the subscribers back to the OLT. Both the upstream and the downstream bandwidths have to be time-shared among all ONUs, to keep the cost of the access network low and economically feasible for subscribers. In order to make PONs more economical, the full service access network (FSAN) consortium was formed by several telecommunication operators in 1995, so as to standardize the common requirements and services for PONs. The FSAN recommendations were later adopted by the International Telecommunication Union (ITU) as the ITU-T G.983 Broadband PON (B-PON) standards (ITU-T Recommendation G.983.1, 1998; ITU-T Recommendation G.983.2, 2000; ITU-T Recommendation G.983.3, 1998). In a B-PON, the separation between the OLT and the ONU is 20 km and each OLT can serve up to 32 ONUs. The downstream traffic at 622-Mb/s is carried by a 1.49-μm optical carrier, while the upstream traffic at 155-Mb/s is carried by a 1.3-μm optical carrier, both of which adopt time-division multiple access (TDMA) for bandwidth sharing among all ONUs. The 1.55-μm wavelength window is reserved for analog video overlay. In 2003, ITU has released the ITU-T G.984 recommendations for the next generation PON, called Gigabit-capable PON (G-PON) (ITU-T Recommendation G.984.1, 2003; ITU-T Recommendation G.984.2, 2003; ITU-T Recommendation G.984.3, 2003), in which the transmission speeds in downstream and upstream directions are increased to 2.5 Gb/s and 1.25 Gb/s / 2.5 Gb/s, respectively. It has also adopted the framing mechanism based on generic framing procedure (GFP). In 2001, IEEE 802.3 standard group also started the 802.3ah working group (IEEE 802.3ah EFM), to standardize the transport of Ethernet frames on PONs (EPON) (Kramer & Pesavento, 2002), due to the popularity of Ethernet in both metro and access arenas. It specifies a symmetric transmission speed of 1 Gb/s for both downstream and upstream traffic, with 16 ONUs per OLT. In recent years, the advent of the 10-Gb/s Ethernet technology is also enhancing the transmission speed of PONs to the 10-Gb/s regime.

In general, all of these PON standards mentioned above are based on simple power splitting at the RN and adopt TDMA to share the transmission bandwidth among all ONUs. The number of ONUs supported is limited by the power budget as well as the bandwidth sharing. Moreover, media access control (MAC) protocol is needed to coordinate the transmission of the upstream data packets from all ONUs so as to avoid any possible collision at the RN. The work in (Kramer, Mukherjee, & Pesavento, 2002) is a good example of a dynamic bandwidth allocation protocol designed for EPON. Furthermore, the