Next-Generation Optical Access Networks

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INTRODUCTION

Fiber-to-the-home/building (FTTH/B) networks have been long advocated as the holy grail of broadband access, but they currently represent only 9% of the subscriptions in the Organization for Economic Co-operation and Development (OECD) countries. This situation is expected to change dramatically over the next years and decades.

Although point-to-point fiber access networks may be the preferred approach in some deployment scenarios with high population densities and short distances, point-to-multipoint passive optical networks (PONs) are poised to play a key role in realizing FTTH/B networks in a cost-efficient and environmentally friendly manner. PONs not only offer huge capacity, small attenuation loss, low operational expenditures, longevity, and future proofness, but also provide the lowest energy consuming solution for broadband access, clearly outperforming optical point-to-point access networks as well as hybrid fiber-copper based access technologies and wireless access solutions, e.g., WiMAX, in terms of energy per bit. This property assures that PONs will play an important role in response to concerns about the greenhouse impact of the Internet, especially given that access networks dominate the total power consumption of today's Internet (Tucker, 2009).

In this article, the main fiber access network architectures are first reviewed. Next, the most promising next-generation passive optical networks are described. Finally, the ongoing and future research directions are discussed.

BACKGROUND

Fiber access networks have in general one of the following three architectures: (*i*) point-to-point architecture, (*ii*) active star architecture, or (*iii*) passive star architecture.

In the point-to-point (PtP) architecture, each home or building is connected to the central office (CO) via one or two dedicated fibers. This type of architecture provides improved privacy and ease of service upgrade for individual subscribers, but requires a large number of fibers and transceivers since network equipment is not shared among subscribers. As a consequence, footprint and power consumption may become serious problems at the CO.

This shortcoming is avoided in star architectures, where a single feeder fiber runs from the CO to a remote node, from which individual distribution fibers branch out to connect the subscribers. The feeder fiber carries all traffic of the attached subscribers and its cost can be shared among them. In doing so, the number of required fibers and transceivers at the CO can be reduced significantly. Depending on the nature of the remote node, the star architecture may be either active or passive. In the active star architecture, the remote node is an active device, e.g., Ethernet switch, and needs powering and maintenance. Conversely, in the passive star architecture, the active node is replaced with a passive optical splitter/combiner. Using a completely passive splitter/combiner at the remote node avoids the need for powering and maintenance and thereby helps reduce the capital expenditures (CAPEX) and in particular operational expenditures (OPEX) of fiber access networks (Koonen, 2006).

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Due to their completely passive nature, PONs incur lower CAPEX and OPEX and also offer a higher reliability than active star architectures. Furthermore, PON outside plants provide transparency against data rate, modulation format, and protocol as the passive splitter/combiner is entirely agnostic to all of them. This transparency, apart from the huge bandwidth and low loss of optical fiber, is one of the most crucial features that eased carriers into deploying PON-based fiber access networks that are instrumental in minimizing deployment costs while maximizing revenues from new service offerings and can be flexibly upgraded as new technologies mature or new standards evolve (Effenberger, 2007).

The nomenclature introduced by Full Service Access Network (FSAN) is now common for most PONs (Shumate, 2008). The service provider's interface to a PON is referred to as optical line termination or optical line terminal (OLT). The OLT is located at the CO together with other equipment such as switches, servers, and routers, which connect the PON to the backbone network. In fiber-to-the-x (FTTx) deployments such as fiber-to-the-cabinet (FTTCab) or fiber-to-the-curb (FTTC), where fiber does not pave all the way to the subscriber, the remote unit is called an optical network unit (ONU). The termination of the DSL copper drop line from the ONU to the premises is called the network termination equipment (NTE). In the case of fiber-to-the-home (FTTH) or fiber-to-the-building (FTTB) networks, where the fiber terminates at the premises, the active network unit at the subscriber is called an optical network termination (ONT). The all-optical passive portion of the PON between OLT and ONU/ONT is referred to as optical access network (OAN) or optical distribution network (ODN).

Typically, PONs have a tree topology with the OLT located at the root and ONUs/ONTs attached to the leaf nodes of the tree. It is worthwhile to mention that PONs offer some topological flexibility in that the splitter can be placed anywhere in the OAN according to given deployment scenarios (Shumate, 2008). For instance, in rural areas, the splitter may be placed far from the OLT close to a group of connected homes in order to capitalize on the cost sharing of a longer feeder fiber in such a fiber-lean PON configuration. Conversely, in urban areas with high population densities a fiber-rich PON configuration may be preferable by locating the splitter at the OLT and running short point-to-point distribution fibers to the nearby subscribers. Even though such a fiber-rich configuration does not benefit from the cost sharing of a common feeder fiber, there are other benefits that make this configuration attractive in urban areas with generally short distances to the subscribers. Similar to the point-to-point architecture, a fiber-rich PON configuration simplifies upgrades of individual subscribers. Unlike point-to-point solutions, however, it requires only a single optical-electrical interface at the OLT. Another interesting PON configuration can be realized by using multiple splitters instead of a single one. This configuration is very helpful to better map splitters to the physical location of home clusters and thereby shorten the length of required distribution fibers to individual homes.

NEXT-GENERATION PASSIVE OPTICAL NETWORKS

Network operators are seeking next-generation passive optical network (NG-PON) solutions that can transparently coexist with legacy PONs on the existing fiber infrastructure and enable gradual upgrades in order to avoid costly and time consuming network modifications and stay flexible for further evolution paths. NG-PONs are mainly envisioned to (*i*) achieve higher performance parameters, e.g., higher bandwidth per subscriber, increased splitting ratio, and extended maximum reach than current state-of-the-art ITU-T G.984.x Gigabit PON (GPON) and IEEE 802.3ah/av 1/10 Gb/s Ethernet PON (EPON) architectures, and (*ii*) broaden GPON/EPON functionalities to include, among others, the consolidation of optical access, metro, and backhaul networks, and their seamless integration with their wireless counterparts, giving rise to hybrid fiber-wireless (FiWi) broadband access networks, as explained in greater detail in the next section.

NG-PONs 1 and 2

According to (Kani, 2009), NG-PON technologies can be divided into the following two categories:

NG-PON 1: This type of technology allows for an *evolutionary* growth of existent Gigabit-class PONs and supports their coexistence on the same ODN. The coexistence is intended to let custom-