Modern Passive Optical Network (PON) Technologies

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INTRODUCTION

Presently, not only the European Union (EU) but the global community faces a decisive priority to "redesign" its economy and society, in order to meet a variety of challenges imposed by the expansion of innovative technological features, in the scope of the new millennium. The rate of investments performed and the rapid development of electronic communications networks-infrastructures, together with all associated facilities in the scope of broadband evolution, create novel major opportunities for the related market sectors (Chochliouros, & Spiliopoulou, 2005). Modern digital-based technologies make compulsory new requirements for next-generation components and for much wider electronics integration. This critical challenge also raises the issue for considering the "evolution" from current large legacy infrastructures towards new (more convenient) ones, by striking a "balance" between backward compatibility requirements and the need to explore disruptive architectures to appropriately build (and offer) future Internet, broadband, and related service infrastructures. More specifically, for the entire European market a number of evolutionary initiatives, as they currently have been encouraged by the latest EU strategic frameworks, relate first and foremost to the technological expansion and the exploitation of ubiquitous broadband networks, the availability/accessibility of dynamic services platforms, and the offering of "adequate" trust and security, all in the framework of converged and interoperable networked environments (European Commission, 2006).

However the global information society cannot deliver its major benefits without a "suitable" and appropriately deployed infrastructure, able to fulfill all requirements for increased bandwidth. During recent years, optics and photonics have become increasingly pervasive in a broad range of applications. Therefore, photonic components and subsystems are nowadays indispensable in multiple application areas, and consequently they constitute concerns of high-strategic importance for many operators. In this critical extent, fiber is constantly becoming an essential priority for wired access, as it can provide excessive bandwidth and additional advantages, if compared to similar alternative options of underlying infrastructures (Agrawal, 2002). There are several market and investment evidences demonstrating that a significant part of next-generation access networks will be based on optical access (Chochliouros, Spiliopoulou, & Lalopoulos, 2005).

This is due to the fact that we are presently witnessing an extraordinary expansion in bandwidth demand, mainly driven by the development of sophisticated services/applications, including video-on-demand (VoD), interactive high-definition digital television (HDTV), IPTV, multi-party videoconferencing, and many more. These facilities require both the existence and the use of a "fitting" underlying network infrastructure, capable of supporting high-speed data transmission rates that cannot be fulfilled by the "traditional" copper-based access networks. In fact, market actors are currently focusing on developing and deploying new network infrastructures (Leiping, 2005) that will constitute future-proof solutions in terms of the anticipated worldwide growth in bandwidth demand (reaching a rate of 50% to 100% annually), but at the same time be economically viable (Prat, Balaquer, Gene, Diaz, & Fiquerola, 2002). To this aim, fiber-access technologies evolve quite rapidly as they can guarantee "infinite" bandwidth opportunities, for all prescribed market needs, either corporate and/or residential.

BACKGROUND

A great majority of users currently benefit from rather high-speed communication services offered through DSL (digital subscriber line) access technologies. DSL's deployment has been widely supported by incumbent operators, as they were able to exploit their already laid copper infrastructure to offer broadband connectivity services to their customers, without being actually obliged to realize severe investments in access infrastructure. However, such schemes are considered as "short-term" market solutions, since the aging copper-based infrastructure is rapidly approaching its essential speed limits, while simultaneously, modern applications definitely "push" data rates beyond the capabilities of such networks. As a consequence, such networks "generate" a type of "limitation" (or a "bottleneck") concerning requirements of bandwidth and service provision between the operator and the end user. In contrast to this option, optical access architectures allow communication via optical fibers and can provide significant advantages to the customers' needs mainly by providing a fully practical (and viable) solution to the access network "bottleneck problem," as they can support extremely high and symmetrical bandwidth to the end user (Green, 2006). Furthermore, they future-proof the network operator's CAPEX investment, as they offer simple and low-cost speed upscale, whenever necessary. While the cost of installing optical access networks has been considered as "extremely high" in the past, this has been falling progressively, and such infrastructures currently seem to be the main broadband access technology of the decade (Frigo, Iannone, & Reichmann, 2004). Optical access networks are not a new concept, as they have been considered as a potential solution for the subscriber access network for quite some time. Their deployment costs as well as their corresponding equipment costs have been dramatically reduced in recent years. Current experience has demonstrated that once fiber is installed, no significant additional investments (or reengineering) are likely to be required for the next few decades; in fact, fiber-based networks can offer fast and easy repair, low-cost maintenance, and simple upgrade. The specific category of Passive Optical Networks (PONs)—as explained in detail in the subsequent parts of this article—are now viewed as probably the "best solution" for bringing fiber to the home, since they are composed of only passive elements (fibers, splitters, splicers, etc.) and are therefore very low priced. In addition, a PON can support very high bandwidths and can function at long distances (of up to 20 km) significantly higher than these supported by high-speed DSL variants.

PON ARCHITECTURE AND DEPLOYMENT

The advent of video-on-demand and interactive gaming has prompted the deployment of immense broadband infrastructures. Because of its large bandwidth, passive optical networks are currently seen as a "proper" technology to make this happen. PON technology, nowadays being broadly adopted and deployed in multiple areas all over the world (with remarkable growth rates in North America and Japan where it provides the main solution for fiber-to-the-home (FTTH) exploitation), constitutes a convenient solution for exploiting the "undoubted" and beneficial usage of the broadband perspective (Gumaste, & Anthony, 2004; Cisco Systems, 2007).

PONs allow individual homes, larger residential or office buildings, and wider premises to be connected to public telecommunications networks directly via fiber with a high bit rate. Even across great distances, they provide users with a very high transfer capacity, which is essential for all modern data services such as high-resolution television reception or home entertainment services. PON is a very recent, *and still developing,* access technology based on the specification originally developed by the Full Service Access Network (FSAN) vendor consortium (http://www.fsanweb.org/) for the APON (ATM (asynchronous transfer mode)- based passive optical network) case. However, as discussed in a subsequent part of this article, several variants have been deployed, with distinct characteristics (Ramaswami, & Sivarajan, 2002).

A PON is a point-to-multipoint, fiber-to-the-premises network architecture where unpowered optical splitters are used to enable a single optical fiber to serve multiple premises (typically 32 different lines). A relevant configuration reduces the amount of fiber and central office (CO) equipment required, if compared with "traditional" point-to-point architectures. The "deletion" of active components implicates that the access network consists of one bi-directional light source and a number of passive splitters that divide the data stream into the individual links to each customer (Kramer & Mukherjee, 2000; Green, 2006). A PON system typically consists of optical line terminals (OLTs), optical network terminals (ONTs), optical network units (ONUs), and passive splitters, as shown in Figure 1**.**

The OLT is located in the network operator's CO in a telecommunications application, or in the CATV (cable TV) provider's head-end. The OLT can either generate optical signals on its own, or pass optical signals (e.g., synchronous optical network–SONET) from a collocated optical cross-connect or other device, broadcasting them downstream through one or more ports. The OLT provides the interface between the PON and the backbone network. These typically include: standard time division multiplexed (TDM) interfaces such as SONET/SDH (synchronous digital hierarchy) or PDH (plesiochronous digital hierarchy) at various rates, Internet protocol (IP) traffic over gigabit or 100 Mbit/s Ethernet, and ATM UNI (user-network interface) at 155-622 Mbit/s.

The ONU or the ONT terminate the circuit at the far end. An ONT is a single integrated electronics unit, and it is used to terminate the circuit inside the premises in an FTTP (fiber-to-the-premises) scenario, where it serves to interface the optical fiber to the copper-based inside wire. In fact, it presents the native service interfaces to the user.

An ONU is the PON-side half of the ONT, terminating the PON; it may present many converged interfaces (such as xDSL or Ethernet) towards the user. It typically requires a separate subscriber unit to provide native user services such as telephony, Ethernet data, or video. In practice, the difference between an ONT and ONU is frequently ignored, and either term is used generically to refer to both classes of equipment (Mukherjee, 1997). The ONU is used in an FTTC (fiber-to-the-curb) scenario, where the fiber stops at the curb, with the balance of the local loop being provisioned over

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