Chapter 1

Introduction: Access networks

This chapter provides an introduction to the rapidly emerging access network services and technologies. It starts with an outline of modern telecommunication networks widely deployed to connect customers with a core network via an access network, and subsequently points out the total bandwidth demand that is required to provide the present and future online services for each customer. Examples of access network technologies are reviewed with the aim to demonstrate that passive optical networks (PONs) are highly desirable to fully support the increasing demand for bandwidth-intensive applications articulated by distance learning, online gaming, Web 2.0 applications and high-definition movie delivery. Finally, this is followed by a review of current deployment of PON architectures worldwide, offering broad perspective of the diverse trends owing to different needs and business plans of network operators.

1.1 Modern telecommunication networks

Shown in Figure 1-1, a modern access network, connecting the local exchange with residential and business customers, spans over distances of a few to tens of kilometres, depending on transmission medium and architectural approach, consists typically of a feeder span and a distribution span, also known as the first mile [1], to deliver triple-play services including voice, data and video over copper and/or optical fibre links. Depending also on network configuration, the remote node between the first mile and the feeder sections can be either active or passive, utilised to aggregate and distribute all data between the customers and local exchange. The local exchange, often referred as the central office (CO), is the gateway to the metropolitan network which connects all COs, usually in a large city or region via a fibre optic ring topology that spans over tens to hundreds of kilometres. It is also in charge of delivering data, voice and video services from service providers to customers. In the end of the chain, the metropolitan network is terminated at the core network, interconnecting cities and different regions over distances of hundreds to thousands of kilometres usually constructed in a mesh topology [2].

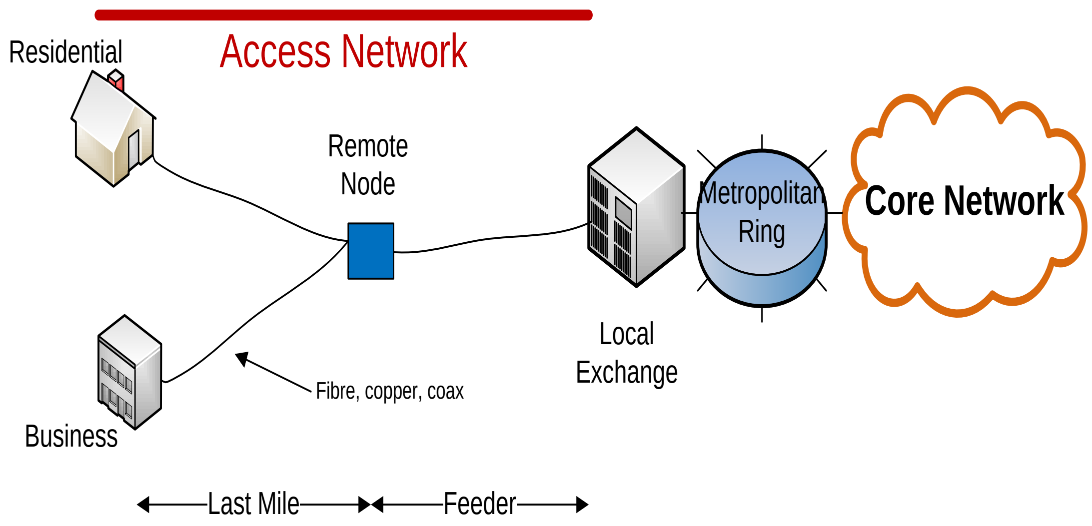

Figure 1-1 A model of the access, metropolitan and core networks

1.2 Access network technologies

The bandwidth demand in access networks has been increasing rapidly over the recent years. Residential and business customers demand access solutions that have high bandwidth, offering media-rich applications [1] including high-definition television (HDTV), video-on-demand (VoD), online gaming, voice-over-IP (VoIP) and high-speed Internet as summarised in Table 1-1.

Table 1-1 Bandwidth estimation for a single residential customer [3]

Service	***Bandwidth***	***Comments***
3 HDTV channels per residential at 20 Mbit/s each	60 Mbit/s	Three HDTV channels
Education-on-demand, online gaming, Internet	10 Mbit/s	Peer-to-peer require symmetrical bandwidth
Video conference of video phone	2 Mbit/s	Requires symmetrical bandwidth
Remote control and sensing	1 Mbit/s	Requires symmetrical bandwidth
Total	**73 Mbit/s**	**Downstream: 73 Mbit/s** **Upstream: 53 Mbit/s**

As shown in Table 1-1, a single HDTV channel encoded by MPEG2 [3] requires approximately 20 Mbit/s. Consequently, based on an estimation of three television sets per home, it is expected that three HDTV channels operating concurrently will be used by a single residential customer in addition to services such as high-speed Internet and video phone, allowing for a total bandwidth in the range of 73 Mbit/s is thought to be sought by subscribers in downstream in the near future [3, 4]. In upstream, mainly driven by symmetrical bandwidth service requirements including online gaming, video-conferencing and education-on-demand in tandem with high-speed Internet and content generation, bandwidth allocations reaching 53 Mbit/s will be needed [3]. By adding forthcoming services such as remote backup and Web 2.0 applications, the required bandwidth for a single residential customer or small business is eventually expected to grow symmetrically to even 100 Mbit/s according incumbent initiatives [5].

To that extent, access network technologies in excessive deployment and increasing development include wireless and wireline alternatives, employed to satisfy low field deployment cost and high bandwidth provision respectively. According to the standards, worldwide-interoperability-for microwave-access (WiMAX) [6] and wireless-fidelity (WiFi) [7] could provide point to multipoint wireless broadband access at up to 70 Mbit/s for distances of 5 km and 50 Mbit/s for 100 meters respectively, nevertheless currently not viable to support high-speed Internet and media-rich video applications since the relatively low aggregate bandwidth is shared among tens to hundreds of users [8].

The predominant broadband wireline access technology deployed currently is the digital subscriber line (DSL) over copper. Unlike wireless, DSL is a point to point architecture capable of providing each subscriber with up to 24 Mbit/s downstream using its flavour such as ADSL2plus [9]. However, due to bandwidth restrictions of the copper medium as well as being a noise-limited technology, the effective subscriber bandwidth depends on local loop copper lengths. To allow subscribers to receive compelling Internet and video services at 30 Mbit/s in downstream and 1 Mbit/s in upstream, local loop lengths must be shorten to approximately 1000 meters [8]. Subsequently and due to the ever increasing bandwidth demand, enhancements in DSL have led to the development and recent deployment of very-high-bit-rate DSL (VDSL) connections capable of providing up to 50 Mbit/s in downstream [10]. In VDSL a further penetration of the feeder fibre deep into the access network is required, leading to hybrid fibre access networks by shortening local loop lengths to a maximum of 100 meters [8]. As shown in Figure 1-2, in the fibre-to-the-curb/cabinet (FTTC) architecture, the fibre may reach up to an optical network unit (ONU) located in a street cabinet, from where twisted pair copper lines extend to the customer premises.

The deeper penetration of the fibre all the way to the subscriber is considered as the ultimate technology to meet the ever increasing bandwidth demand, makes it the ideal candidate to meet the capacity challenges in the access network at present and in the foreseeable future.

Consequently, due to the widespread adoption of the Ethernet protocol in local networks and the increasing demand for high-speed access networks, active Ethernet fibre-to-the-home (FTTH) architectures have been extensively investigated and standardised [11]. Among these access network architectures, an Ethernet router/switch can be deployed in either the street cabinet for a point to multipoint topology or in the local exchange for a point to point topology, using multimode and single-mode fibres to provide subscribers with data rates in the range of 100 Mbit/s to 1 Gbit/s depending on distances and the type of fibre used. In that sense, placing an active device in the street cabinet requires high capital expenditures (CAPEX) in addition to high operational expenditures (OPEX) due to the need for electrical power monitoring and maintenance of backup batteries in the street cabinet [8]. Moreover, such a network is not transparent to different signal formats and data rates, consequently in case the network is to be upgraded to support higher data rates or different transmission protocols it requires replacing the electronics in the street cabinet [8]. On the contrary, placing the switch in the local exchange results in a large number of fibres reaching the local exchange, though allows virtually unlimited bandwidth per subscriber due to dedicated connections to subscribers and upgradability to higher speeds on subscriber by subscriber basis.

Passive optical networks have evolved to provide simplicity and low network costs. The PON is a typical point to multipoint optical access network based on either an FTTH or fibre-to-the-building (FTTB) infrastructure, connecting the optical line terminal (OLT) in the local exchange with many residential and business customers by means of passive splitters located in the field, as shown in Figure 1-2. PONs require lower CAPEX since no active components are employed in the field, which in turn leads to lower OPEX since there is no need to maintain components operation as well as avoiding power failures. In addition, due to the agnostic nature of the

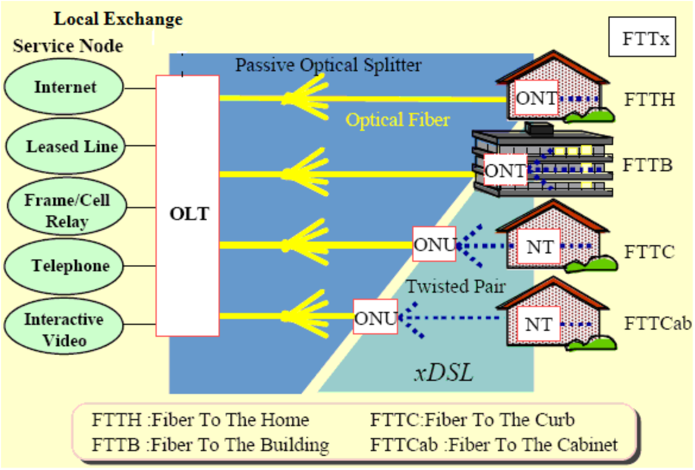

Figure 1-2 Fibre-to-the-x architectures [12]

passive splitter, a PON-based access network is optically transparent, capable of supporting diverse protocols, higher transmission speeds and additional wavelengths [8]. PON standards based on time division multiplexing (TDM), including the Ethernet PON (EPON) [13] and the Gigabit-capable PON (GPON) [14-17], have been developed and formalised to offer triple-play services to residential and business subscribers in the access network [18].

Consequently, they have been largely adopted and deployed mostly in Asia and North America in contrast to Europe that is moving forward with several fibre deployment projects so far [19].

1.3 Current FTTH deployment worldwide

Throughout Europe there are currently 1 million FTTH subscribers [19] based on GPON networks, although the number of connected homes is approximately 2.6 million [20] with a forecast of 4 million FTTH subscribers by 2010 [21]. Currently, as a result of regulatory uncertainties, there are several fibre deployment projects in Europe, initiated both by new network operators and incumbents, mostly located in Sweden, Italy, France, Germany, Denmark, Netherlands and Norway [19].

On the contrary, South Korea has maintained high broadband service penetration rate with current rapid growth of approximately 7 million subscribers requesting triple-play services in excess of 50 Mbit/s [3] and as a result approximately 12 million subscribers are expected to be served by 2010 [3, 22]. According to bandwidth demand, cost and future upgradeability, wavelength division multiplexing (WDM)-PON based FTTH has been chosen to be deployed primarily although has not been standardised yet, in contrast to the rest of Asia and the United States, capable of delivering triple-play services at symmetrical bandwidth of 155 Mbit/s per subscriber [4, 23]. The WDM-PON provides virtual point to point connections through designated wavelengths allowing for dedicated bandwidth per subscriber, protocol transparency and increased security [4].

The Japanese broadband market is also entering into a total FTTH age. Although initially FTTH was used only for Internet access, at present, network providers employ mainly EPON systems to provide up to 100 Mbit/s per customer focusing on triple-play services as the main drive to full-scale FTTH [24]. The FTTH market in Japan continues to grow rapidly as the number of both small/medium enterprises and residential customers have exceeded 10 million [19] with a target of serving 30 million customers by 2010 [20, 24] by means of creating attractive applications that are available only on FTTH. Out of the current customer number, the vast majority is residential, demonstrating that FTTH has been accepted not only to provide services to enterprises but also for ordinary consumers [24].

In the Hong Kong region, around 23 percent of households are presently connected with FTTH [19]. The first provider, Hong Kong Broadband Network Limited (HKBN), to launch FTTH with 100 Mbit/s and 1 Gbit/s services in 2005, has been operating GPON at 2.5 Gbit/s downstream since the beginning of 2008, delivering advanced triple-play services, and is planning to increase its FTTH coverage from 1.4 million to 2 million home connected within the next few years [25].

Finally, in the United States there are currently 10 million [19] FTTH connections with the aim to exceed 18 million households by 2010 [26], out of which nearly 2 million [19] residential and businesses customers are currently receiving services by Verizon as the main player in addition to other suppliers. Recently, GPON has been receiving more attention and has already been in deployment in undeveloped areas, offering single downstream and upstream speeds at 2.5 Gbit/s and 1.25 Gbit/s respectively for distances of 20 km.

1.4 Research drive and outline

This research programme has been widely driven by the escalating deployment of PON technologies which unavoidably is expected to steer the attention of telecomm operators, providers, vendors and the research community towards medium as well as longer term solutions. The former has been naturally generated by the deployment issues risen in the request of accommodating varying network penetration and servicing in the presence of diverse geographical areas while the later driven primarily by researchers and standardisation bodies aiming to provide the next generation PONs that would lead the way of development from time multiplexing to wavelength over a single network.

In both scenarios characteristics such as transparency, scalability, dynamicity and migration capability are essential ingredients to provide end-users with real-time bandwidth on demand with minimum service disruption. From the operators point of view, optical transparency and ability to scale-up user numbers and data rates flexibly are vital properties to keep capital and operational costs effectively low, particularly since the cost of components required for deploying the already proposed but not yet standardised WDM-PON cannot be currently justified.

Following the review of FTTH worldwide deployment initiatives, chapter 2 concentrates on the operational characteristics of PON standards and potential next-generation PON solutions by assessing the various research directions. Subsequently chapter 3 presents an innovative routing scheme employing a coarse array waveguide grating (AWG) to multiplex closely-spaced wavelengths into coarse ITU-T grids, exhibiting coarse-fine grooming to guarantee network simplicity, interoperability of various technologies and increased scalability. Consequently, chapter 4 presents the proposed access network architecture utilising the coarse channels of an AWG and potential wavelength-independent end user equipment to demonstrate dynamicity among TDM and WDM-PONs, with coarse-fine grooming features. This is pursued by chapters 5 and 6, demonstrating the complete modelling and assessment evaluation of the access network elements by means of incorporating a reflective transceiver in the wavelength-independent end user equipment and a novel method to achieve network full-duplex operation for increasing the bandwidth utilisation of the network. For the purpose of validating the simulation work, chapter 7 demonstrates experimentally the performance of the coarse-routed, multi-PON access network architecture using a readily-available AWG. Finally, chapter 8 serves the purpose of summarising the studies conducted throughout this research programme and subsequently discussing the potential evolution and technical challenges of the network to span all the way to the core nodes in a long-reach access infrastructure.

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