Preface

We are currently witnessing an unprecedented growth in bandwidth demand, which is mainly driven by the development and proliferation of advanced broadband multimedia applications, including video-on-demand, high-definition digital television (HDTV), multi-party videoconferencing, online gaming and many others. These multimedia digital services are highly bandwidth intensive, and therefore require underlying access network infrastructures that are capable of supporting the very high-speed data transmission rates that are needed. It is apparent that today’s conventional broadband access communications networks (such as xDSL networks) will quickly become “bottlenecks” in terms of bandwidth provision. Hence, telecom providers are currently focusing on developing new network infrastructures that will constitute future-proof solutions in terms of the anticipated growth in bandwidth demand, but at the same time be economically viable.

Indeed, while most users currently enjoy relatively high speed communication services mostly through xDSL networks, purely copper-based access networks can be viewed as relatively short-term solutions since this aging infrastructure is rapidly approaching its fundamental speed limits. In contrast, fiber optics-based technologies offer tremendously higher bandwidth, a fact that has long been recognized by all telecom providers at international level, which have upgraded their core networks to optical technologies. Having won the battle in core networks, optical networks are now entering the access networks arena, reducing or even totally eliminating the need for data transfer over conventional telephone wires.

It should be emphasized that optical access networks are not a new concept, but instead have been considered as a solution for the subscriber access network for quite some time. Early proposals and developments can even be traced back to the early 80s. However, these were abandoned due to the technology not being mature enough, and most importantly, due to prohibitively high costs coupled with the fact that there was no actual bandwidth demand to necessitate the deployment of such networks at the time. Nevertheless, since then, photonic and fiber-optic components technology has progressed remarkably and volume production has dramatically reduced costs. The cost of deploying such networks is also falling steadily, and coupled with the ever-increasing bandwidth demand, mass worldwide optical access networks deployment is now reality. Fiber access networks are capable of delivering extremely high bandwidth at large distances and can cater for all current and predicted future voice, data and video services requirements. In this sense, it can be said that “once fiber is installed, no significant further investments or re-engineering is likely to be required for decades”.

Also referred to as “Fiber-to-the-X” (FTTX, where X can be Home, Node, Building etc. depending on the degree of optical fiber penetration), such architectures offer a viable solution to the access network bottleneck problem, and promise extremely high bandwidth to the end-user. In addition, they future-proof the telecommunications operator’s investment, as they offer relatively easy upgrade and upscale, should
such a need arises in the future. Deployment projects are now underway in Asia, the USA and Europe, creating an international diversity of distinct business cases, which all provide major contribution to the global effort for promoting broadband and creating opportunities for an “Information Society for All”.

This book presents a comprehensive overview of the emerging optical access network solutions that promise to cater for current and predicted future voice, data and video services needs, and ultimately change the way we experience broadband. With a thematically wide selection of chapters that are written by renowned researchers of the field, the book provides a well-rounded and thorough overview of the current and upcoming state-of-the-art optical access networks, discussing technological, regulatory, business and deployment aspects, based on current international trends, policies and applied measures.

The core objective of the book is two-fold: It intends to discuss the challenge imposed by fibre-optic access networks worldwide as a strategic choice (or even as a “necessity” due to rapid technology and market development) of market operators, in order to provide immediate “responses” to the fast evolutionary progress in bandwidth demand. To this aim, apart from the exact analysis of all underlying strategic initiatives, we discuss and evaluate specific technology trends in order to realize the expected beneficial use of optical access infrastructures, as a “modern” and viable network solution. On the other hand, we deal with current market cases and assess several potential opportunities observed at the global level, by discussing and analyzing specific cases (as currently appear in Asia, America and Europe). The current diversity among international markets can also reflect other trends explaining why in some cases such networks have been very rapidly deployed (and have already affected growth by contributing to the national economies) while in others there are still “limitations” and uncertainties, preventing from further growth. This option is quite important, especially in the scope of liberalized and competitive markets, as any further delay may result to negative results for further economy progress.

The book presents a comprehensive overview of the emerging optical access network solutions, that promise to efficiently meet the anticipated growth in bandwidth demand by delivering extremely high data rates to end-users, and offering truly unprecedented levels of performance that can cater for all current and predicted future voice, data and video services.

The book provides comprehensive coverage of the area of optical access networks, covering not only technology, but also real-world deployment, business and economical issues. Hence, a very well-rounded source of information is concentrated on a single book

Written primarily from a general perspective and at the same time not aimed at the experienced engineer, a very wide audience can benefit from this book. Most technical background is included and explained within it, focusing only on the most important issues and avoiding unnecessary specialised technicalities. Overall, the book provides up-to-date authoritative information in a single-source, and is useful for anyone who wishes to introduce himself or deepen and update his knowledge in this fascinating field. Specifically, the book is intended to serve as a valuable source of information to readers coming from a wide range of different professional disciplines including postgraduate science and engineering students, academics and researchers, telecommunication engineers and technicians, communication network planners and designers, ICT business development strategists, telecommunication market analysts and many others.

The book is organized into thirteen distinct chapters, which together capture a very wide range of timely issues regarding optical access networks.

Chapter 1, by Ioannis P. Chochliouros, George A. Heliotis and Anastasia S. Spiliopoulou is entitled *An Introduction to Optical Access Networks: Technological Overview and Regulatory Issues for Large-Scale Deployment* and gives comprehensive review of the emerging optical access solutions, focusing
mainly on passive optical network (PON) technologies and contrasting their capabilities to conventional copper-based broadband solutions. The chapter discusses the present global challenge for extended bandwidth provision in the scope of the fast developing electronic communications sector, creating a fully converged environment and it examines several potential options imposed by distinct technologies, as currently adopted in the marketplace and experienced by the various categories of the “market actors”. The chapter also analyzes, in detail, the regulatory issues that surround the deployment of such next generation networks, and surveys current deployment efforts and applied policies, as well as potential perspectives for further growth and development, on a worldwide level (with distinct paradigms chosen from the international experience).

Chapter 2, by William Yue and Brian Hunck of the Fujitsu Network Communications Inc. (USA) is entitled *Optical Access Comes of Age in a Packet-Delivery World* and reviews the current and upcoming “flavors” of optical access networks and the migration from direct copper loops to such optical architectures. Competitive pressure to provide high-bandwidth services (such as video) to consumers, and Ethernet transport to enterprises, is forcing service providers to rebuild their access networks. To this aim, more optical fibers are being added in the last mile to meet these new bandwidth demands since legacy access networks have not been sufficient to support bandwidth-intensive applications. Key business drivers such as carrier competition, bandwidth needs, and reliability and service level agreement issues of optical technology are discussed. The chapter also considers the near future of optical access product trends and some key optical deployment options.

Chapter 3, by Gerasimos C. Pagiatakis of the School for Pedagogical and Technological Education, Greece, is entitled *Active Optical Access Networks*, and focuses on optical access networks in which the sharing of fibers among end-users is implemented by means of active equipment. In active optical access networks (AONs), user-side units, known as optical network units, are usually grouped in access synchronous digital hierarchy (SDH) rings and fiber-interconnected to a local exchange unit, known as optical line termination. In AONs (as well as in passive optical networks) the optical fiber (originally used in the trunk network) is introduced in the access domain, namely between the customer and the local exchange. Practically, this means that the huge bandwidth provided by the optical fiber becomes directly available to the normal user. Despite the obvious financial and techno-economical issues related to the massive deployment of optical access networks, the possibilities and challenges created are enormous. The chapter examines in detail the various units and modules that comprise an active optical access network as well as their respective role, and it presents the fundamental procedures for implementing such a network.

Chapter 4, by Calvin C.K. Chan of the Chinese University of Hong Kong, Hong Kong, is entitled *Wavelength Division Multiplexed Passive Optical Networks: Principles, Architectures and Technologies* and presents a very comprehensive treatment of the principles and network architectures of Wavelength Division Multiplexed Passive Optical Networks (WDM-PONs), as well as a thorough discussion of their enabling technologies. Wavelength division multiplexing 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 requirement 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. Different feasible approaches to support the two-way transmission are discussed, as WDM-PON seems as an “attractive solution” to realize fiber-to-the-home (FTTH) applications.
Chapter 5, by Chi-Wai Chow of the National Chiao Tung University, Taiwan, is entitled *Broadband Optical Access using Centralized Carrier Distribution* and discusses the main characteristics, advantages and attractive features of WDM-PONs with centralized carrier distribution. Wavelength division multiplexed (WDM) PON improves the utilization of fiber bandwidth through the use of wavelength domain. A cost-effective solution in WDM PON would use the same components in each optical networking unit (ONU), which should thus be independent of the wavelength assigned by the network. Optical carriers are distributed from the head-end office to different ONUs to produce the upstream signals. Various solutions of colorless ONUs are discussed. The chapter also analyzes the technical challenges that these implementations present, focusing on Rayleigh backscattering (RB) induced impairments and proposing attractive solutions for their mitigation, with some novel PONs highlighted.

Chapter 6, by Noemí Merayo, Patricia Fernández, Ramón J. Durán, Rubén M. Lorenzo, Ignacio de Miguel and Evaristo J. Abril by the University of Valladolid, Spain, is entitled *Bandwidth Allocation Methods in Passive Optical Access Networks (PONs)* and thoroughly discusses the various PON standards that exist as well as the technology for long-reach implementations, focusing on the main challenges that these present relative to bandwidth allocation methods, quality of service (QoS) and service level agreement (SLA) issues. PONs appear as quite suitable architectures to face today’s access challenges; this technology “shows” a very cost saving architecture, it provides a huge amount of bandwidth and efficiently supports QoS. In PON networks, as all subscribers share the same uplink channel, a medium access control protocol is required to provide a contention method to access the channel. As the performance of Time Division Multiplexing Access (TDMA) protocol is not good enough because traffic nature is heterogeneous, Dynamic Bandwidth Allocation (DBA) algorithms are proposed to overcome the problem. These algorithms are very efficient as they adapt the bandwidth assignment depending on the updated requirements and traffic conditions.

Chapter 7, by Jun Zheng and Hussein T. Mouftah of the University of Ottawa, Canada, is entitled *Dynamic Bandwidth Allocation for Ethernet Passive Optical Networks*, and gives an extensive introduction to the critically important bandwidth allocation mechanisms in Ethernet-PON (EPON) systems. In an EPON system, multiple optical network units (ONUs) share a common upstream transmission channel for data transmission. To efficiently utilize the limited bandwidth of the upstream channel, a system must dynamically allocate the upstream bandwidth among multiple ONUs based on the instantaneous bandwidth demands and quality of service requirements of end users. The chapter discusses the major challenges in designing protocols for bandwidth allocation, and presents an overview of the state-of-the-art dynamic bandwidth allocation (DBA) algorithms that are proposed for EPON implementations.

Chapter 8, by Miklós Molnar, Fen Zhou and Bernard Cousin of the Institut de Recherche en Informatique et Systèmes Aléatoires (INISA) and of the Université de Rennes-I, France, is entitled *Multicast Routing in Optical Access Networks* and discusses multicasting as an instrumental feature for the efficient delivery of multimedia services in future optical access networks. Widely available broadband services in the Internet require high capacity access networks and optical networking is able to efficiently provide the huge bandwidth required by multimedia applications, producing large amounts of data traffic, typically between several distinct types of terminals. Multicast is a bandwidth-efficient technique for one-to-many or many-to-many communications, and will be instrumental in serving multimedia applications in future optical access networks, requiring robust and reliable connections together with compliance to QoS criteria. The chapter gives an extensive analysis of multicast routing methods in a variety of optical access network architectures, focusing on performance and dependability issues.

Chapter 9, by Angélique Rissons and Jean-Claude Mollier of the Université de Toulouse, France, is
entitled *The Vertical-Cavity Surface-Emitting Laser: A Key Component in Future Optical Access Networks* and relates to photonic instrumentation that is utilized in optical access networks, focusing on the emerging and promising technology of Vertical Cavity Surface-Emitting Lasers (VCSELs). For more than ten years, the access network market is “attracted” by the VCSEL technology. This chapter aims at highlighting the tremendous emergence of the VCSEL technology in the FTTX systems, especially by providing an overview of the advances, the physical behavior, and the various structures regarding VCSELs. The technology, features and physical behaviour of these laser sources are thoroughly analyzed, highlighting their advantages and potential for use in optical access networks systems. Diverse system configurations to generate a signal for the optical access networks and potentials of network architectures are discussed. The VCSEL is probably one of the most important and promising components of the “last-leg” optical access networks.

Chapter 10, by Vagia Kyriakidou, Aristidis Chipouras, Dimitris Katsianis and Thomas Sphicopoulos of the University of Athens, Greece, is entitled *Business Models for Municipal Metro Networks: Theoretical and Financial Analysis*, and gives a solid understanding of techno-economic evaluation of optical access networks. Broadband penetration is continuously increasing and operators have to face end users’ demand for more bandwidth. More specifically, in Europe, initiatives towards the development of optical networks infrastructures have been undertaken to address the need of faster and more telecommunications services. New infrastructures and equipment are required to deliver real broadband services to end users and, consequently, the implementation of appropriate business model seems to be meaningful tool for infrastructures as it could ensure commercial viability and limit investment’s risks. After reviewing important current cases of worldwide deployment, the chapter discusses and analyzes a variety of business models for the emerging optical access network markets, highlighting the main issues that should be addressed by the main actors involved, including telecommunication operators, infrastructure constructors, and so forth.

Chapter 11, by Jürgen Schussmann and Thomas Schirl of the Carinthia University of Applied Sciences, Austria, is entitled *Modeling and Techno-Economic Evaluations of WDM-PONs*, and considers the bandwidth and capacity requirements that are posed by future services, emphasizing and analyzing in detail the solutions that WDM-PON networks can offer. In the near future, broadband access networks will be required with data rates of over 1Gbit/s per customer. Currently, time-division multiple access passive optical networks (TDMA-PONs) are deployed; however, these networks cannot keep up with the requirements for the broadcasting of a great number of HDTV channels and the unicasting of several triple-play services (i.e., voice, data and video). In contrast, WDM PONs will be able to provide these required high data rates per user causing higher costs than with TDM-PONs. The chapter presents detailed techno-economic evaluations of single- and multi-stage WDM-PONs, also discussing design issues and identifying and analyzing the most promising network architectures in terms of cost effectiveness. Access to these newly identified network architectures will prompt market introduction as well as market penetration helping Fiber-to-the-Home (FTTH) to become reality.

Chapter 12, by Christos Vassilopoulos of the Hellenic Telecommunications Organization S.A., Greece, is entitled *The New Generation Access Network*, and gives an extensive review of current and upcoming access networks implementations, focusing on a strategic analysis of their prospects in view of the complicated multi-player telecommunications environment, involving telecommunications Operators (both Incumbent Local Exchange Carriers-ILECs and Competitive Local Exchange Carriers-CLECs), regulators and other pressure interest groups. The chapter offers a qualitative approach towards the development of the new generation access network, based on FTTx implementations. After a brief de-
scription of the current state of traditional access networks and an estimation of the expected data rate per household in terms of services, the chapter examines all the available network technologies (FTTx), access technologies (xDSL, Ethernet and PON) for both point-to-point (P2P) and point-to-multipoint (P2MP) development schemes and their relevant implementations. The chapter also outlines different deployment strategies that could be followed for optimal development.

Chapter 13, by Tetsuya Yokotani of the Mitsubishi Electric Corporation, Japan, is entitled “Next Generation Home Network and Home Gateway associated with Optical Access”, and discusses the importance of home gateways for the efficient provisioning of services to the end-users of next generation access networks. As optical broadband access networks have been popularized, triple play services using IP technologies, such as Internet access, IP telephony, and IP video distributing services, have been also popularized. However, consumers expect new services for a more comfortable life. Especially, when QoS guarantee and high reliable services are provided in NGN (Next Generation Network) era, various home network services over NGN are deployed. For this purpose, the home gateway has been installed in consumer houses for the connection between access and home networks. The chapter analyzes in detail the functional characteristic, as well as the service features that home gateways should possess, that is: high performance for IP processing; compliance with the interface of carrier grade infrastructure including NGN; flexible platform for various services, and; easy management and maintenance. The chapter also discusses their standardization efforts and progress, and proposes evolution scenarios from the present to the future.

The combination of the selected chapters included in the book (all composed by recognised experts in the relevant thematic “fields”) provides a detailed analysis of the relevant scope, bringing together ideas and experience from the academic and the business sector, thus “joining together” current market trends and research priorities, from a worldwide scope. As the proposed book covers a great variety of issues (i.e. technical, strategic, social, regulatory and business) all relevant to a major challenge for promoting broadband-based market evolution and deployment, it will provide essential facilities to any potential reader (mainly by offering exact and updated information to a great audience of potential recipients, of multiple origin, i.e. from researchers to market players, from students to authorities, etc.). Thus, its “value” for new scientists, for investors and for market players will be extremely high.

As can be seen from the above short chapter summaries, the book provides a solid foundation on optical access networks, and also captures the great diversity of current issues affecting their real-world deployment and future perspectives. We trust that the book will prove valuable for those who will read it, and hope it will allow a thorough understanding of the current and upcoming FTTx implementations and will promote strategic thinking for future issues.

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