Funding Application for Joint Applied Research Projects
PN-II-PT-PCCA-2011-3

Project

"Optical Wireless – based Multi-Gb/s Hybrid Access Network for Broadband Multiservices Applications"

OWHAN

This is a grant proposal for a nationally funded project in Romania, signed off by **4 (four)** research institutions and universities in Romania. The grant proposal text body is found at **pages 9-16**. The other pages talk about the project members, institutions, etc.

This grant proposal was asking for **465,000 EURO (2 MILLION RON) from the public budget** (see page 2 below, and page 37), the maximum that could be claimed, as specified in the national call for proposals from 2011. Of this sum, **80%** was planned to be spent on personnel + indirect costs and only 6% on equipment and materials.

As can be seen on **pages 9-16**, this proposal contains a very large proportion from other works, in all sections (including *objective, original, novel and innovative nature,* and *state of the art*). **5 (five) different sources were identified as having been plagiarized**, none of which mentioned or referenced in the current proposal. These sources are color-coded and listed below:

Source #1	S. Sarkar, S. Dixit, B. Mukherjee (IEEE Fellow), "Hybrid Wireless-Optical Broadband-Access Network (WOBAN): A Review of Relevant Challenges", IEEE Journal of Lightwave Technology, vol. 25, no. 11, Nov 2007 ***[invited journal article]***
Source #2	H. Willebrand, B.S. Ghuman, "Free space optics: enabling optical connectivity in today's networks", SAMS Publishing, 2002 ***[book]***
Source #3	R. Ramaswami, K.N. Sivarajan, G. Hajime Sasaki, "Optical Networks: A Practical Perspective", 3rd Ed, Elsevier (Morgan Kaufmann Publishers), 2010 ***[book]***
Source #4	B. Mukherjee, "Optical WDM networks", Springer Science, 2006 ***[book]***
Source #5	H. Zhu, H. Zang, K. Zhu, B. Mukherjee, "A Novel Generic Graph Model for Traffic Grooming in Heterogeneous WDM Mesh Networks", IEEE/ACM Transactions on Networking, Vol.11, no.2, April 2003 ***[journal artilcle]***

The original name and acronym as they appear in Source #1 are *"Hybrid Wireless-Optical Broadband-Access Network"*, and acronym *"WOBAN"*.

Project Proposal

Executive summary
Optical Wireless-based Multi Gb/s Hybrid Access Network for Broadband multiservices Applications (OWHAN) is a promising architecture intended for being deployed as municipal access solutions and hard to reach areas access solutions. OWHAN is combining optical wireless, wireless, fiber and wirelines to compel solution that optimize the best of the optical and wireless access. This project presents relevant research challenges, namely, network setup, network connectivity, and fault-tolerant behaviour of the OWHAN. OWHAN provides much higher bandwidth for multiservices applications than current solutions, as well as deeper fiber penetration. OWHAN combines the high capacity of optical fiber with the 10 Gb/s traffic speed of the optical wireless and the low installation and maintenance cost of a passive infrastructure. OWHAN is essentialy a wavelength division multiplex (WDM)-based solution, therefore the network provides high scalability to support multiple wavelengths over the same fiber infrastructure, it is inherently transparent to the channel bit rate, and it may not suffer power-splitting losses. The OWHAN architecture can be employed to benefit from (a) the reliability, robustness, and high capacity of wireline optical technologies and (b) the flexibility (anytime, anywhere) and cost savings of a wireless network. The objectives of the project: 1. To provide each end user with whenever needed, 100 Mb/s traffic bit rate; 2. To quickly and easily deploy flexible and scalable bandwidth throughout the access network; 3. Security within an OWHAN network; 4. Mobility within an OWHAN network; 5. Dissemination of partial and final results regarding the OWHAN network. The innovative nature of the project is regarding the migration of DWDM solutions into the access arena, wavelength on demand, DWDM services to independent carriers, high connectivity, and high scalability. **The project will result in thorough analysis of the optical wireless-based multi Gb/s optical access network, models of scalable, flexible, high connectivity, and cost effective optical access network, and solution for multicasting schemes, traffic grooming and collisions.**

Source #1, page 1, from abstract

Source #1, page 1, top-right

Source #1, page 1, middle-right

Source #1, page 1, bottom-right

Source #1, page 3, top-right

Source #1 actually states that a WDM Passive Optical Network (PON) has those qualities, not a hybrid wireless solution.

(authentic text reveals sloppy English)

Hybrid Wireless-Optical Broadband-Access Network (WOBAN): A Review of Relevant Challenges

Suman Sarkar, *Student Member, IEEE*, Sudhir Dixit, *Senior Member, IEEE*, and Biswanath Mukherjee, *Fellow, IEEE*

(Invited Paper)

***Abstract*—The hybrid wireless-optical broadband-access network (WOBAN) is a promising architecture for future access networks. Recently, the wireless part of WOBAN has been gaining increasing attention, and early versions are being deployed as municipal access solutions to eliminate the wired drop to every wireless router at customer premises. This architecture saves on network deployment cost because the fiber need not penetrate each end-user, and it extends the reach of emerging optical-access solutions, such as passive optical networks. This paper first presents an architecture and a vision for the WOBAN and articulates why the combination of wireless and optical presents a compelling solution that optimizes the best of both worlds. While this discussion briefly touches upon the business drivers, the main arguments are based on technical and deployment considerations. Consequently, the rest of this paper reviews a variety of relevant research challenges, namely, network setup, network connectivity, and fault-tolerant behavior of the WOBAN. In the network setup, we review the design of a WOBAN where the back end is a wired optical network, the front end is managed by a wireless connectivity, and, in between, the tail ends of the optical part [known as optical network unit (ONU)] communicate directly with wireless base stations (known as "gateway routers"). We outline algorithms to optimize the placement of ONUs in a WOBAN and report on a survey that we conducted on the distribution and types of wireless routers in the Wildhorse residential neighborhood of North Davis, CA. Then, we examine the WOBAN's routing properties (network connectivity), discuss the pros and cons of various routing algorithms, and summarize the idea behind fault-tolerant design of such hybrid networks.**

***Index Terms*—Architecture, broadband access, fault tolerance, optical network, routing, wireless network.**

A PON provides much higher bandwidth for data applications [than current solutions such as digital subscriber line (DSL) and cable modem (CM)], as well as deeper fiber penetration. Based on current standards, a PON can cover a maximum distance of 20 km from the OLT to the ONU. While fiber-to-the-building, fiber-to-the-home (FTTH), or even fiber-to-the-PC solutions have the ultimate goal of fiber reaching all the way to end-user premises, fiber-to-the-curb may be a more economical deployment scenario today [1], [2].

The traditional single-wavelength PON (also known as the time-division-multiplexed PON or TDM-PON) combines the high capacity of optical fiber with the low installation and maintenance cost of a passive infrastructure. The optical carrier (OC) is shared by means of a passive splitter among all the users, so the PON topology is a tree, as in most other distribution networks, e.g., those for power, voice, video, etc. As a consequence, the number of ONUs is limited by the splitting loss and by the bit rate of the transceivers in the OLT and in the ONUs. Current specifications allow for 16 ONUs at a maximum distance of 20 km from the OLT and 32 ONUs at a maximum

Gigabit PON (GPON), Generic Framing Procedure PON (GFP-PON), etc.] to Wavelength-Division-Multiplexed PON (WDM-PON) is essential. A WDM-PON solution provides excellent scalability because it can support multiple wavelengths over the same fiber infrastructure, it is inherently transparent to the channel bit rate, and, depending on its architecture, it may not suffer power-splitting losses (see [3] for a review of WDM-PON architectures).

The WOBAN architecture can be employed to capture the best of both worlds: 1) the reliability, robustness, and high capacity of wireline optical communication and 2) the flexibility ("anytime–anywhere" approach) and cost savings of a wireless network. A WOBAN consists of a wireless network

"wireless or" was added compared to original text from Source #1, which raises question wrt. the architecture (wireless as a back end network?)

These red paragraphs ar part of the objectives. Since they are found in the abstract of Source #1 *(which actually does review the setup and presents the algorithms and routing properties)*, **this raises suspicions about the work that the authors of this grant proposal would have undergone if funded.**

Of note are also the attempts to slightly change the text, which makes less sense and reveals sloppy English (e.g. "*in beetwin*").

1. Importance and Relevance of the Technical and/or Scientific Content

1.1. Concept and objectives:

1.1.1 Concept of the project.

The optical wireless-based hybrid access network (OWHAN) is a promising architecture intended for being deployed as municipal access solutions and hard to reach areas access solutions. OWHAN is combining optical wireless, wireless, fiber and wirelines to compel solution that optimize the best of the optical and wireless access. This project presents relevant research challenges, namely, network setup, network connectivity, and fault-tolerant behaviour of the OWHAN.

The network setup review the design of an OWHAN where the front end is an optical wireless connectivity, the back end is a wireless or a wired optical subnetwork, and, in beetwin, the tail ends of the optical network unit (ONU) communicate directly with gateway routers.

The project presents algorithms to optimize the placement of ONUs in an OWHAM. Then, the project examines the routing properties (network connectivity), and deals with the fault-tolerant design of such hybrid networks.

OWHAN provides much higher bandwidth for multiservices applications than current solutions, as well as deeper fiber penetration. Based on current standards, the optical wireless-based hybrid access network may cover up to 20 km from the optical line terminal (OLT) in the central office (CO) to the ONU. Fiber-to-the-building (FTTB), fiber-to-the-home (FTTH) or fiber-to-the-curb (FTTC) solutions have the ultimate goal of fiber reaching all the way to end-user premises.

OWHAN combines the high capacity of optical fiber with the 10 Gb/s traffic speed of the optical wireless and the low installation and maintenance cost of a passive infrastructure. The optical carriers are shared by means of passive splitters among all the users. The number of ONUs is limited by the splitting loss and by the bit rate of the tranceivers in the OLTs and in the ONUs.

OWHAN is essentialy a wavelength division multiplex (WDM)-based solution, therefore the network provides high scalability to support multiple wavelengths over the same fiber infrastructure, it is inherently transparent to the channel bit rate, and it may not suffer power-splitting losses.

OWHAN employes a separate wavelength channel from the OLT to each ONU, both in the upstream and downstream directions. This approache creates a point-to-point link between the OLT and each ONU. Each ONU can operate at the full bit rate of a wavelength channel. Different wavelengths may be operated at different bit rates, if necessary; hence, different types of services may be supported over the network.

Source #1, page 1, from abstract

Source #1, page 1, top-right.

Source #1, page 1, middle-right

Source #1, page 1, bottom-right

Source #1, page 2, top-left

Hybrid Wireless-Optical Broadband-Access Network (WOBAN): A Review of Relevant Challenges

Suman Sarkar, *Student Member, IEEE*, Sudhir Dixit, *Senior Member, IEEE*, and Biswanath Mukherjee, *Fellow, IEEE*

(Invited Paper)

***Abstract*—The hybrid wireless-optical broadband-access network (WOBAN) is a promising architecture for future access networks. Recently, the wireless part of WOBAN has been gaining increasing attention, and early versions are being deployed as municipal access solutions to eliminate the wired drop to every wireless router at customer premises. This architecture saves on network deployment cost because the fiber need not penetrate each end-user, and it extends the reach of emerging optical-access solutions, such as passive optical networks. This paper first presents an architecture and a vision for the WOBAN and articulates why the combination of wireless and optical presents a compelling solution that optimizes the best of both worlds. While this discussion briefly touches upon the business drivers, the main arguments are based on technical and deployment considerations. Consequently, the rest of this paper reviews a variety of relevant research challenges, namely, network setup, network connectivity, and fault-tolerant behavior of the WOBAN. In the network setup, we review the design of a WOBAN where the back end is a wired optical network, the front end is managed by a wireless connectivity, and, in between, the tail ends of the optical part [known as optical network unit (ONU)] communicate directly with wireless base stations (known as "gateway routers"). We outline algorithms to optimize the placement of ONUs in a WOBAN and report on a survey that**

the Wildhorse residential neighborhood of North Davis, CA. Then, we examine the WOBAN's routing properties (network connectivity), discuss the pros and cons of various routing algorithms, and summarize the idea behind fault-tolerant design of such hybrid networks.

***Index Terms*—Architecture, broadband access, fault tolerance, optical network, routing, wireless network.**

A PON provides much higher bandwidth for data applications [than current solutions such as digital subscriber line (DSL) and cable modem (CM)], as well as deeper fiber penetration. Based on current standards, a PON can cover a maximum distance of 20 km from the OLT to the ONU. While fiber-to-the-building, fiber-to-the-home (FTTH), or even fiber-to-the-PC solutions have the ultimate goal of fiber reaching all the way to end-user premises, fiber-to-the-curb may be a more economical deployment scenario today [1], [2].

The traditional single-wavelength PON (also known as the time-division-multiplexed PON or TDM-PON) combines the high capacity of optical fiber with the low installation and maintenance cost of a passive infrastructure. The optical carrier (OC) is shared by means of a passive splitter among all the users, so the PON topology is a tree, as in most other distribution networks, e.g., those for power, voice, video, etc. As a consequence, the number of ONUs is limited by the splitting loss and by the bit rate of the transceivers in the OLT and in the ONUs. Current specifications allow for 16 ONUs at a maximum distance of 20 km from the OLT and 32 ONUs at a maximum

Gigabit PON (GPON), Generic Framing Procedure PON (GFP-PON), etc.] to Wavelength-Division-Multiplexed PON (WDM-PON) is essential. A WDM-PON solution provides excellent scalability because it can support multiple wavelengths over the same fiber infrastructure, it is inherently transparent to the channel bit rate, and, depending on its architecture, it may not suffer power-splitting losses (see [3] for a review of WDM-PON architectures).

The straightforward approach to build a WDM-PON is to employ a separate wavelength channel from the OLT to each ONU, both in the upstream and downstream directions. This approach creates a point-to-point (P2P) link between the OLT and each ONU, which differs from the P2MP topology of the traditional PON. In the WDM-PON, each ONU can operate at a rate up to the full bit rate of a wavelength channel. Moreover, different wavelengths may be operated at different bit rates, if necessary; hence, different types of services may be supported over the same network. This is clearly an advantage of WDM-

These statements contradict each other: (1) top sentence suggests ***fiber*** is the back-end network, (2) third red highlight suggests ***fiber or wireless*** is the back-end network, (3) this highlight suggests ***wireless*** is the back-end network. **These contradictions do not exist in Source #1.**

***"wireless"* replaced with *"fiber or wireless"*. The new meaning is also questionable (run fiber as far as possible from the CO and then again fiber taking over?)**

(1)

The concept of the project is to run fiber optics as far as possible from the CO to the end user and then having fiber or wireless access technologies take over. Running fiber optics to every end user premises from the CO could be costly; in addition, wireless access from CO to every end user is not possible due to limited spectrum. Therefore OWHAN may be an excellent compromise to optimize the engineering design of how far the fiber should penetrate before wireless takes over.

The OWHAN architecture can be employed to benefit from (a) the reliability, robustness, and high capacity of wireline optical technologies and (b) the flexibility (anytime, anywhere) and cost savings of a wireless network. A OWHAN is a optical wireless network at the front end, and it is supported by an

(2) fiber or wireless network at the back end. The OWHAN is dominated by the optical wireless and the passive optical access technologies. Different passive optical network (PON) segments can be supported by a CO, with each PON segment radiating from the CO. The head end of each PON segment is driven by an OLT via an optical wireless system. The tail end of each PON segment contains a number of ONUs, which typically serve end user in a standard PON architecture. The ONUs can be connected to wireless base stations (BS) for the wireless portion of the OWHAN. The wireless BSs are gateway routers of both the optical domain and the wireless domain. Besides theese gateways, the wireless back end of a OWHAN consists of other wireless routers/BSs to efficiently manage the network. Thus, the

(3) back end of a OWHAN might be essentially a multihop wireless mesh network with several wireless routers and a few gateways (to connect to the ONUs, and, consequently, to the rest of the Internet through OLTs/CO). the wireless portion of the OWHAN may employ standard technologies such as WiFi or WiMax. Since the ONUs will be located far away from the Co, efficient spectrum reuse can be expected across the BSs with much smaller range but with much higher bandwidth. Thus, the OWHAN is able to support a much larger user base with high bandwidth needs.

The OWHAN architecture assumes that an OLT is placed in a CO and that it feeds several ONUs. From ONUs to the CO there is a fiber optics network that assembles in into an optical wireless terrestrial laser system. From ONUs, end users are wirelessly connected (in single-hop or multi-hop fashion) or wireline connected (VDSL, coax fashion, FTTx).

1.1.2 The project objectives

The objectives of the project:

1. To provide each end user with whenever needed, 100 Mb/s traffic bit rate;
2. To quickly and easily deploy flexible and scalable bandwidth throughout the access network;
3. Security within an OWHAN network;

Source #1, page 3, bottom-left & top-right

Source #1, page 3, top-right

"wireless" replaced with "optical wireless" and "optical" with "fiber or wireless". These raise questions about the architecture (wireless as back-end network?) and reveal sloppy English.

Changed from *"front end"* to *"back end"*, which raises questions about the architecture (wireless as back-end network?)

Source #1, page 4, bottom-left & top-right

(authentic text reveals sloppy English.)

The concept of a hybrid WOBAN is a very attractive one. This is because it may be costly in several situations to run fiber to every home (or equivalent end-user premises) from the telecom CO; in addition, providing wireless access from the CO to every end-user may not be possible because of limited spectrum. Thus, running fiber as far as possible from the CO toward the end-user and then having wireless-access technologies take over may be an excellent compromise. How far should fiber penetrate before wireless takes over is an interesting engineering design and optimization problem.

A WOBAN consists of a wireless network at the front end, and it is supported by an optical network at the back end (see Fig. 1). Noting that the dominant optical-access technology today is the PON, different PON segments can be supported by a telecom CO, with each PON segment radiating away from the CO. Note that the head end of each PON segment is driven by an OLT, which is located at the CO. The tail end of each PON segment will contain a number of ONUs, which typically serve end-users in a standard PON architecture. However, for the proposed hybrid WOBAN, the ONUs will connect to wireless BSs for the wireless portion of the WOBAN. The wireless BSs that are directly connected to the ONUs are known as wireless "gateway routers," because they are the gateways of both the optical and the wireless worlds. Besides these gateways, the wireless front end of a WOBAN consists of other wireless routers/BSs to efficiently manage the network. Thus, the front end of a WOBAN is essentially a multihop wireless mesh network with several wireless routers and a few gateways (to connect to the ONUs and, consequently, to the rest of the Internet through OLTs/CO). The wireless portion of the WOBAN may employ standard technologies such as WiFi or WiMax. Since the ONUs will be located far away from the CO, efficient spectrum reuse can be expected across the BSs with much smaller range but with much higher bandwidth; thus, this WOBAN can potentially support a much larger user base with high bandwidth needs.

The WOBAN architecture assumes that an OLT is placed in a telecom CO and that it feeds several ONUs. Thus, from ONU to the CO, we have a traditional fiber network; moreover,

from ONUs, end-users are wirelessly connected (in single-hop or multihop fashion).

4. Mobility within an OWHAN network;
5. Dissemination of partial and final results regarding the OWHAN network.

1.1.3 Emphasise the original, novelty and innovative nature of the project

The innovative nature of the project:

1. Optical wireless system (known as free-space optics as well) bridges the metropolitan DWDM (dense wavelength division mutiplexing) ring and the optical access network. As metropolitan DWDM systems migrate into the access arena, they will be supporting both SDH and native data services, increasing the requirement for protection, and restoration in the optical domain;
2. Wavelength on demand. Idle wavelengths can be quickly allocated to carriers through the implementation of optical switching systems. These systems allow an operator to treat the optical layer of the network much like it treats the ATM layer: as a pool of available bandwidth within a cloud to be quickly allocated in virtual optical circuits. The virtual optical cirfcuits are new optical circuits that are managed by optical switching systems using constraint-based routing algorithms. The optical edge equipments can be agile enough with wavelengths so as the carriers may offer users the opportunity to purchase wavelength services not as a fixed lease but as a flexible service;
3. DWDM services. Optical wireless is integrating DWDM into the access network so as independent players would be able to build their own fiber rings, yet might own only part of the ring. This solution saves rental payment to incumbent local exchange carriers, which are likely to take advantage of this situation;
4. High connectivity. The connectivity bottleneck is shifting from the metropolitan gateway towards the edge of the access optical network. That allows the cost per bit to decrease and makes the optical capacity available to the end users;
5. High scalability. The combination between optical wireless and WDM-PON solutions into a flexible optical access network enables cost effective, accelerated optical networking into multiple areas and not just last mile.

1.1.4 Expected results of the project end products.

1. Thorough analysis of an optical wireless-based multi Gb/s optical access network as a solution to high capacity, high speed optical support of broadband multiservices applications at the end users premises;

Source #2, page 96, top

Source #2, page 97, middle

Source #2, page 98, bottom

Source #2, page 99, top

Source #2, page 99, bottom

As metropolitan DWDM systems migrate into the access arena, they will be supporting both SONET and native data services, increasing the requirement for protection and restoration in the optical domain. Simple APS is available today on most vendors' equipment, whereas others

In the long-haul world, wavelength on demand is most often found in the literature of national wholesale network operators. In these networks, idle wavelengths on a backbone trunk can be quickly allocated to other carriers or service providers through the implementation of optical switching systems. These systems allow an operator to treat the optical layer of its network much like it treats the ATM layer: as a pool of available bandwidth within a "cloud" to be quickly allocated in virtual circuits. In the case of optical networks, these virtual circuits are now optical circuits that are managed by optical switching systems using constraint-based routing algorithms. If vendors can develop optical edge equipment that can be agile enough with wavelengths, carriers might find it cost effective in certain instances to offer service providers or major corporate users the opportunity to purchase wavelength services not as a fixed lease or IRU, but as a flexible service. This would require a fully distributed metropolitan DWDM

- DWDM services: With the integration of WDM and FSO systems, independent players aim to build their own fiber rings, yet might own only part of the ring. Such a solution could save rental payment to ILECs, which are likely to take advantage of this situation.

With the evident growth in optical networks, it is clear that the connectivity bottleneck will continue to be shifting problems all across the optical networks. It is also clear that although

work is focused on decreasing the cost per bit and making optical capacity available to the end users. Alas, some dreams are not easily realized, and the vision of the all-optical network finds

To address and enable the acceleration of optical networks while addressing the need to be cost effective, free-space optics is presenting the users with an opportunity to do so. FSO is a perfect fit for the growing MANs fitting into multiple areas and not just last mile. Regardless of

2. Model of a scalable, flexible, high connectivity, and cost effective optical access network for enterprises and users premises;
3. Multicasting solution. A multicasting scheme would allow point-to-multipoint connections and straightforward link-disjoint backup tree;
4. Traffic model. The traffic solution generates the graph and formulates the mathematicals of the traffic grooming;
5. Collisions management solution. The fault management approach designs the traffic rerouting and presents the fault-recovery solutions.

1.2. State of the art:

There is a continuing, relentless need for more capacity in the network. This demand is fueld by a tremendous growth of the Internet and the World Wide Web, both in terms of number of users and the amount of time, and thus bandwidth taken by each user. Internet traffic has been growing rapidly. Estimates of growth have varied considerably over the years, with some early growth estimates showing a doubling every four to six month. Despite the variations, these growth estimates are always high, with more recent estimates at about 50% annualy. Broadband access technologies, which provide 1 Mb/s bandwidth per user, have been deployed widely. Meanwhile, business today relies on high-speed networks to get conducted. The networks are used to interconnect multiple locations within a company as well as between companies for business-to-business transactions. Large corporations are commonly leasing 1 Gb/s connections today.

There is a strong correlation between the increase in demand and the cost of bandwidth. Technological advances have succeeded in continously reducing the cost of bandwidth. This reduced cost of bandwidth in turn spurs the development of new applications that make use of more bandwidth and affects behavioral patterns. This positive feedback cycle shows no sign of abating in the near future.

The traffic in a network is dominated by data as opposed to traditional voice traffic. The legacy network were designed to efficiently support voice rather than data. Today, data transport services are pervasive and are capable of providing quality of service to carry performance sensitive applications such as real time voice and video.

Such factors have driven the development of high-capacity optical networks. Optical networking is the technology of choice for meeting the growing demands for bandwidth in the information society. Today

Not quite an academic or English term.

(authentic text reveals sloppy English.)

Source #3, pages 1-2

Source #3, page 2, middle

Source #4, page 3, bottom

As we begin the new millennium, we are seeing dramatic changes in the telecommunications industry that have far-reaching implications for our lifestyles. There are many drivers for these changes. First and foremost is the continuing, relentless need for more capacity in the network. This demand is fueled by many factors. The tremendous growth of the Internet and the World Wide Web, both in terms of number of users and the amount of time, and thus bandwidth taken by each user, is a major factor. Internet traffic has been growing rapidly for many years. Estimates of growth have varied considerably over the years, with some early growth estimates showing a doubling every four to six months. Despite the variations, these growth estimates are always high, with more recent estimates at about 50% annually. Meanwhile, broadband access technologies such as digital subscriber line (DSL) and cable modems, which provide bandwidths per user on the order of 1 Mb/s, has been deployed widely. For example, in 2008 about 55% of the adults in the United States had broadband access at home, while only 10% had access through dialup lines of 28–56 kb/s. Fiber to the home has shown steady growth with Asian markets showing the highest market penetration.

At the same time, businesses today rely on high-speed networks to conduct their businesses. These networks are used to interconnect multiple locations within a company as well as between companies for business-to-business transactions. Large corporations that used to lease 155 Mb/s lines to interconnect their internal sites are commonly leasing 1 Gb/s connections today.

There is also a strong correlation between the increase in demand and the cost of bandwidth. Technological advances have succeeded in continously reducing the

1

2 Introduction to Optical Networks

cost of bandwidth. This reduced cost of bandwidth in turn spurs the development of a new set of applications that make use of more bandwidth and affects behavioral patterns. A simple example is that as phone calls get cheaper, people spend more time on the phone. This development in turn drives the need for more bandwidth in the network. This positive feedback cycle shows no sign of abating in the near future.

Also, traffic in a network is dominated by data as opposed to traditional voice traffic. In the past, the reverse was true, and so legacy networks were designed to efficiently support voice rather than data. Today, data transport services are pervasive and are capable of providing quality of service to carry performance sensitive applications such as real-time voice and video.

These factors have driven the development of high-capacity optical networks and

gineering solutions to meet the growing bandwidth needs of our information society.

Optical networking using wavelength-division multiplexing (WDM) – the term WDM will be explained shortly in this chapter – is the technology of choice for meeting these growing demands [Mukh97, Mukh00]. While there may be an abundance of dark fiber and WDM transmission capacity today, there have been existing an abundance of dark fiber and WDM transmission capacity, still a tremendous need for optical switching equipment, high-capacity, high-density optical crossconnects, for managing high-capacity optical signals, rises up.

The access network enables end-users (business and residential customers) to get connected to the rest of the network infrastructure. The access network spans a distance of a few kilometers. The current access solutions are dial-up modems, high-speed lines, digital subscriber lines, and cable modem. However, the access network continues to be a bottleneck, and users require higher bandwidth to be delivered to their machines. Passive optical networks based on inexpensive, proven, and ubiquitus Ethernet technology is an attractive proposition for this market. With fiber now directly available to office buildings in metropolitan areas, networks based on SDH or Ethernet-based technologies are being used to provide high-speed access to large business users.

Efforts to develop high-capacity access networks were devoted to developing networks that would accommodate various forms of video, such as video-on-demand and high-definition television. However, the range of services that users are expected to demand in the future is vast and unpredictible. Today, end-users are interested in both Internet access and other high-speed data access services, for such applications as telecommuting, distance learning, entertainment video, and videoconferencing. Future, unforeseen applications are to arise and make ever-increasing demands on the bandwidth available in the last kilometer. At a broad level, the services can be classified based on three major criteria. The first is the bandwidth requirement, which can vary from a few kilohertz for telephony to tens of megabits per second per video stream or even tens of gigabits per second for high-speed leased lines. The second is weather this requirement is symmetric, for example, videoconferencing, or asymmetric, for example, broadcast video. Today, while most business services are symmetric, other services tend to be asymmetric, with more bandwidth needed from the service provider to the user (the downstream direction) than from the user to the service provider (the upstream direction). The last criterion is whether th eservice is inherently broadcast, where every user gets the same information, for example, broadcast video, or whether the service is switched, where different users get different information, as in the case with internet access.

Different combinations of services and network topologies are made possible – a broadcast service may be supported by a broadcast or a switched network, and a switched service may be supported by a broadcast or a switched network. Broadcast networks may be cheaper than switched networks, are well tailord for delivering broadcast services, and have the advantage that all the interface units are identical, making them easier to deploy. Switched networks are well suited for delivering switched services and

Source #4, page 3, bottom

Identical typo as in Source #4 (should read *"modems"*).

Source #4, page 4, bottom

Replaced from "*last mile*".

"*last kilometer*" is not really a term.

(authentic text reveals sloppy English.)

Source #3, pages 629-630

Source #3, page 631, bottom

may be an abundance of dark fiber and WDM transmission capacity today, we believe that there is – and there will continue to be – a tremendous need for optical switching equipment, namely high-capacity and high-density optical crossconnects (OXCs), for managing high-capacity optical signals. These

The access network enables end-users (businesses and residential customers) to get connected to the rest of the network infrastructure. The access network spans a distance of a few kilometers (perhaps up to 20 km as some local exchange carriers (LECs) seem to prefer). Our current solutions for access are dial-up modems, higher-speed lines (such as T1/E1), digital subscriber line (DSL), and cable modem. However, the access network continues to be a bottleneck, and users require (and are demanding) higher bandwidth to be delivered to their machines. How to provide this high bandwidth in an inexpensive manner is a key R&D priority. Passive optical networks (PONs) based on inexpensive, proven, and ubiquitous Ethernet technology (and referred to as EPON) seem an attractive proposition for this market segment. PON technology in general, and EPON in particular,

---

home or business. With fiber now directly available to many office buildings in metropolitan areas, networks based on SONET/SDH or Ethernet-based technologies are being used to provide high-speed access to large business users. Business users

Early efforts to develop high-capacity access networks were devoted to developing networks that would accommodate various forms of video, such as video-on-demand and high-definition television. However, the range of services that users are expected to demand in the future is vast and unpredictable. Today, end users

are interested in both Internet access and other high-speed data access services, for such applications as telecommuting, distance learning, entertainment video, and videoconferencing. Future, unforeseen applications are also sure to arise and make ever-increasing demands on the bandwidth available in the last mile. The term *full*

At a broad level, these services can be classified based on three major criteria. The first is the bandwidth requirement, which can vary from a few kilohertz for telephony to tens of megabits per second per video stream or even tens of gigabits per second for high-speed leased lines. The second is whether this requirement is *symmetric* (two way), for example, videoconferencing, or *asymmetric* (one way), for example, broadcast video. Today, while most business services are symmetric, other services tend to be asymmetric, with more bandwidth needed from the service provider to the user (the downstream direction) than from the user to the service provider (the upstream direction). The last criterion is whether the service is inherently broadcast, where every user gets the same information, for example, broadcast video, or whether the service is switched, where different users get different information, as is the case with Internet access.

referring to the network topology. Different combinations of services and network topologies are possible—a broadcast service may be supported by a broadcast or a switched network, and a switched service may be supported by a broadcast or a switched network. In a broadcast network, an RN broadcasts the data it receives from

network is a broadcast network. Broadcast networks may be cheaper than switched networks, are well suited for delivering broadcast services, and have the advantage that all the NIUs are identical, making them easier to deploy. (In some switched

Switched networks, as their name suggests, are well suited for delivering switched services and provide more security. For example, it is not possible for one subscriber provide more security. Faukt location is easier in a switched network than in a broadcast network. In broadcast networks, the intelligence is all at the interface units, whereas in switched network, it is in the network. Thus, the network interface units may be simpler in switched networks than in broadcast networks.

Several approaches have been used to upgrade the access network infrastructure to support the emerging set of new services. The integrated service digital network provided 144 kb/s of bandwidth over the existing twisted-pair infrastructure. The digital subscriber line is another technique that works over the existing infrastructure but provides more bandwidth, sophisticated modulation and coding techniques to realize a capacity of a few megabits per second over twisted pair, which is sufficient to transmit compressed video. Satellites provide another way of delivering access services. A satellite may provide more bandwidth than a terrestrial coaxial cable system. However, the amount of spatial reuse of bandwidth is limited, since a single satellite has a wide coverage area within which it broadcasts signals. Wireless access is another viable option. Although it suffers from limited bandwidth and range, it can be deployed rapidly and allows providers without an existing infrastructure to enter the market. Among the variants are multichannel multipoint distribution services (MMDS) and the local multipoint distribution service (LMDS), both of which are terrestrial line-of-sight systems. MMDS provides 33 6 MHz channels in the 2-3 GHz band with a range of 15 to 55 km. LMDS operates in the 28 GHz band with 1.3 GHz of bandwidth and is suitable for short range (3-5 km) deployment in dense metropolitan areas. LMDS is a part of IEEE 802.16 wireless communication standards, commonly known as WiMAX. These standards can provide up to 70 Mb/s of symmetric bandwidth and up to a distance of 50 km. wiMAX can operate in a wide range orf frequencies below 66 GHz, including 2.3 GHz to 3.5 GHz in the licensed spectrum and 5 GHz in the public spectrum.

IEEE 802.11 is a common wireless local-area access technology to the internet. It operates in the 2.5 nad 5 GHz public spectrum and can provide data rates of about 50 Mb/s. They are limited by a very short range of tens of meters to an access point.

Optical wireless systems using lasers transmitting over free space into the home are also being developed as an alternative approach. These systems can provide about 622 Mb/s of capacity over a line-of-sight range of 200 m to 4 km.

In the context of next-generation access network, hybrid fiber coax (HFC) approach and fiber to the curb (FTTC) approach are being considered. The HFC approach is still a broadcast architecdture, whereas the FTTC approach incorporates switching.

Advances in optical networking have made bandwidth-intensive multicast applications, such as HDTV,

Source #3, page 632, bottom

Source #3, pages 635-636

Identical mistake as in Source #3 (should read "2.4"; 2.5 GHz is licensed, not public spectrum).

Source #4, page 561, middle

services and provide more security. For example, it is not possible for one subscriber

corrupt the entire network. Fault location is generally easier in a switched network than in a broadcast network. In broadcast networks, the "intelligence" is all at the NIUs, whereas in switched networks, it is in the network. Thus, NIUs may be simpler in switched networks than in broadcast networks.

Several approaches have been used to upgrade the access network infrastructure to support the emerging set of new services. The *integrated services digital network* (ISDN) provides 144 kb/s of bandwidth over the existing twisted-pair infrastructure. The *digital subscriber line* (DSL) is another technique that works over the existing infrastructure but provides significantly more bandwidth than ISDN. It uses sophisticated modulation and coding techniques to realize a capacity of a few megabits per second over twisted pair, which is sufficient to transmit compressed video. This requires that the central office (CO) and the home each have a DSL

Satellites provide another way of delivering access services. The direct broadcast satellite system uses a geosynchronous satellite to broadcast a few hundred channels to individual homes. A satellite may provide more bandwidth than a terrestrial coaxial cable system. However, the main problem is that, unlike terrestrial systems, the amount of spatial reuse of bandwidth possible is quite limited, since a single satellite has a wide coverage area within which it broadcasts the signals. Also, there

Wireless access is yet another viable option. Although it suffers from limited bandwidth and range, it can be deployed rapidly and allows providers without an existing infrastructure to enter the market. Among the variants are the *multichannel multipoint distribution service* (MMDS) and the *local multipoint distribution service* (LMDS), both of which are terrestrial line-of-sight systems. MMDS provides thirty-three 6 MHz channels in the 2–3 GHz band with a range of 15 to 55 km, depending on the transmit power. LMDS operates in the 28 GHz band with 1.3 GHz of bandwidth and is suitable for short-range (3–5 km) deployment in dense metropolitan areas

in this band). LMDS is part of a family of wireless communication standards, IEEE 802.16 or commonly known as WiMAX. These standards can provide up to 70 Mb/s of symmetric bandwidth and up to a distance of 50 km. They have a variety of applications, including point-to-point links and portable Internet access. WiMAX can operate in a wide range of frequencies below 66 GHz, including 2.3 GHz to 3.5 GHz in the licensed spectrum and 5 GHz in the public spectrum.

A common wireless access technology to the Internet by laptop computers and other personal computing devices is the IEEE 802.11 wireless local-area network technology. It operates in the 2.5 and 5 GHz public spectrum and can provide data rates of about 50 Mb/s. They are limited by a very short range of tens of meters to an access point or "hot spot." These hot spots are often found in airports, coffee

Optical fiberless systems using lasers transmitting over free space into the home are also being developed as an alternative approach. These systems can provide about 622 Mb/s of capacity over a line-of-sight range of 200 to 500 m.

In the context of the next-generation access network, the two main architectures being considered today are the so-called hybrid fiber coax (HFC) approach and the fiber to the curb (FTTC) approach. The HFC approach is still a broadcast architecture, whereas the FTTC approach incorporates switching.

Advances in optical WDM networking have made bandwidth-intensive multicast applications such as HDTV, interactive distance learning, live aucinteractive distance learning, live auctions, distributed games, movie broadcast from studios, etc., widely popuoar. These applications require point-to-multipoint connections from a source node to the destination nodes in a network. Multicasting provides an easy means to deliver messages to multiple destinations without requiring too mush message replication.

Traffic grooming is a practical problem for designing optical networks. Konda & Chow formulates the static traffic grooming problem as an integer linear program and propose a heuristic to minimize the number of transceiver. Brunato & Battiti present several lower bounds for regular topologies, and greedy and iterative greedy schemes are developed. Thiagarajan & Somani consider a dynamic traffic pattern in wavelength division multiplexing mesh networks, and propose a connection admission control scheme to ensure fairness in terms of connection blocking. Cox & Sanchez study the problem of planning and designing a wavelength division multiplexing mesh network with certain forecast traffic demands, to satisfy all the connections as well as minimize the network cost.

In an optical network, a link failure, due to the high capacity of the link, can lead to the loss of a large amount of data. Appropriate protection and restoration schemes, which minimize the data loss when a link failure occurs, are mandatory. Anderson, Doshi, Dravida, and Harshavardhana uses procedures of upper layers of protocols (ATM, IP, MPLS) to recover from link failures. The fault-recovery time in optical layer should be on the order of milliseconds in order to minimize data loss. According to Gerstel, the fault-recovery mechanisms should be considered in the optical layer because (a) the optical layer can efficiently multiplex protection resources (such as spare wavelengths and fibers) among other several higher-layer network applications, and (b) survivability at the optical layer provides protection to higher-layer protocols that may not have built-in fault recovery.

Source #4, page 561, middle

Source #5, page 2, top-left

Source #5, page 2, top-left

Source #5, page 2, middle-left

Source #4, page 755, bottom

tions, distributed games, movie broadcasts from studios, etc., widely popular [Paul98, Mill99, MaZQ98, SuGT01]. These applications require *point-to-multipoint* (PtMP) connections from a source node to the destination nodes in a network. Multicasting provides an easy means to deliver messages to multiple destinations without requiring too much message replication.

an extremely important area of research. The work in [22] formulates the static traffic-grooming problem as an ILP and proposes a heuristic to minimize the number of transceivers. In [23], several lower bounds for regular topologies are presented and greedy and iterative greedy schemes are developed.

of the ILP. The works in [24]–[29] consider a dynamic traffic pattern in WDM mesh networks. In [24], the authors propose a connection admission control scheme to ensure fairness in terms of connection blocking. A theoretical capacity correlation

[28], the problem of planning and designing a WDM mesh network with certain forecast traffic demands, to satisfy all the connections as well as minimize the network cost, is studied. In [29], the authors investigate the design of multilayer mesh

In an optical network, the high capacity of a link has the problem that a link failure can potentially lead to the loss of a large amount of data (and revenue). So, we need to develop appropriate protection and restoration schemes which minimize the data loss when a link failure occurs (see Chapter 11). Relative to the optical layer, upper layers of protocols (such as ATM, IP, and MPLS) have their own procedures to recover from link failures [ADDH94, Huit95, MSOH99]. However, the recovery time for upper layers is significantly larger (on the order of seconds), whereas we prefer that the fault-recovery times at the optical layer should be on the order of milliseconds in order to minimize data losses. Furthermore, it is beneficial to consider fault-recovery mechanisms in the optical layer for the following reasons [Gers98]: (a) the optical layer can efficiently multiplex protection resources (such as spare wavelengths and fibers) among several higher-layer network applications, and (b) survivability at the optical layer provides protection to higher-layer protocols which may not have built-in fault recovery.

- ✓ Give and use new ideas;
- ✓ Improve all communicating skills;
- ✓ Emphasize accountability and control.

A **Consortium Agreement** will state the legal provisions that all the participants in the project obey to. The legal clauses will be regarding internal organization and management of the consortium, copyright issues, disputes, financial issues.

Unfortunate discrepancy.

Also see the comment on page 10 regarding the objectives that appear to be taken from Source #1, which already published them in 2007.

Table 6.

Key persons list				
	Name and surname*	**Scientific title**	**Phase**	**Person-month**
Coordinator (CO)	Dragomir Radu	Dr. eng.	1,2,3,4,5	0.5
	Manea Viorel	eng.	1,2,3,4,5	1
Partner 1	Croitoru Otilia	Dr. eng.	4,5	0.5
	Alexandru Marian	Dr. eng.	4,5	0.5
Partner 2	Lita Ioan	Dr. eng.	1,2,3,4,5	0.5
	Ionita Silviu	Dr. eng.	1,2,3,4,5	0.5
Partner 3	Schiopu Paul	Dr. eng	1,2,3	0.5
	Manea Adrian	Dr. eng.	1,2,3	0.5
Total				

*the CVs will be uploaded on the web platform, www.uefiscdi-direct.ro

The total, although missing, is 4.5 person-month for a duration of 32 months (2.5 years).

Available research infrastructure

1. ICT resources:
   - Desktop PCs (Intel Core 2 Duo, 2 GB RAM DDR2, video RAM 512 MB, HDD 320 GB, DVD-RW, 6x USB 2.0, Ethernet 100/1000, Windows 7 32 bit, Office 2010)
   - Laserjet printer, multifunction 300 dpi
   - Color Inkjet printer
   - LAN
2. Research resources:
   - Matlab Environment

Table 7.	Budget breakdown by year (mii lei)												
	Public Budget				Private cofinancing				Total				Private cofinancing
	2012	2013	2014	Total	2012	2013	2014	Total	2012	2013	2014	Total	%
Coordinator (CO)	300	450	450	1.200					300	450	450	1.200	
Partner 1			320	320								320	
Partner 2	60	120	100	280					60	120	100	280	
Partner 3	120	80		200					120	80		200	
Total	480	650	870	2.000					480	650	870	2.000	

The maximum sum in Euro and Lei that could be claimed, specified in the official 2011 funding call were 465000 Euro or 2000000 Lei.

This gives a ratio of Euro:Lei = 4.301.

Table 8. Budget breakdown by category of expenses

Budget breakdown / destination (lei)[1]								
		Personnel costs	Logistics			Travel	Indirect costs	Total
			Equipments	Materials	Subcontracting			
Coordinator (CO)	Public Budget	781.287	35.000	73.713		77.000	233.000	1.200.000
	Private cofinancing							
Partner 1	Public Budget	192.000	70.000	10.000	5.000	5.000	38.000	320.000
	Private cofinancing							
Partner 2	Public Budget	110.000	28.000	80.000		20.000	42.000	280.000
	Private cofinancing							
Partner 3	Public Budget	160.000					40.000	200.000
	Private cofinancing							
Total		1.243.287	133.000	163.713	5.000	102.000	353.000	2.000.000

[1]According to Chapter 8 – Budget

This gives approx 115600 Euros/year for salaries. Table 6 above shows 4.5 person-month.

Table 9. Justification of purchasing major pieces of equipment

	Equipment name and characteristics	Justification
Coordinator (CO)	Notebook 1 buc Intel Core i3 mobile, 64 bit, RAM 4GB DDR3, HDD 500 GB, cache 8 MB, 7200 rpm, video RAM 1 GB, optical DVD –RW, UTP RJ 45 100/1000 Mb/s, Wi-Fi 802.11/b,g,n, port 4 x 2.0 USB, bluetooth, port SD/MMC, webcam & mick, Windows 7 (64 bit), Office 2010 Pro 64 bit	Mobile work desk
	Software: Optical components, devices, and networking simulator	Optical access network program simulator
Partner 1	1. Wireless and optic simulator program (real-time performance measurements, alarms quality/quantity, compatibility measurements, standard MIBs simulation. 2. PCs (Intel Core i5, HDD 640 GB SATA, RAM 4 GB, DVD SuperMulti, NVIDIA GForce, video RAM 1GB, Ethernet 100/1000, IEEE 802 11 b,g,n. 3. Display 17”	Provide solutions model communications devices, protocols, technologies and architectures and simulate their performance in a dinamic virtual network environment. Enable: • Evaluating and enhancing wireless protocols i.e., WiMAX, WiFi, UMTS, etc. • Designing MANET routing protocols • Analysing optical network design Allow to run software simulators, designing virtual network environment and collision analysing.
Partner 2	Free Space Optics System (Full dúplex, 1400 -1600 nm, tunable laser, min. 10 GB/s, self alignment system, auto-tracking)	Inplementation of the model approach
Partner 3		