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Future optical networks: a review

Raghavendra MV[1*], Subba Rao G[2], Sudheer Raja V[3]

1. Associate Professor, Electrical Engineering Dept, Adama Science & Technology University, Ethiopia, E-mail: miriampally@gmail.com
2. Assistant Professor, Electrical Engineering Dept, Adama Science & Technology University, Ethiopia, E-mail: subbu.electronics17@gmail.com
3. Assistant Professor, Electrical Engineering Dept, Adama Science & Technology University, Ethiopia, E-mail: sudheerrajav@yahoo.com

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ABSTRACT

Progress on research and development in optical networks will be discussed in this paper. Some emerging important topics include hybrid optical-wireless access, long-reach broadband access, dynamic optical circuit switching, robust network design, Ethernet everywhere, etc. This paper presents views on the future of optical networking. A historical look at the emergence of optical networking is first taken, followed by a discussion on the drivers pushing for a new and pervasive network, which is based on photonics and can satisfy the needs of a broadening base of residential, business, and scientific users.

Key words: Optical communications, optical networks.

1. INTRODUCTION

It is challenging to write about our research and development (R&D) priorities on optical networks. However, we all know the need for appropriate technologies and engineering solutions to meet the growing bandwidth needs of our information society with emerging applications such as Internet Protocol TV (IPTV), distributed multi-player network games, peer-to-peer applications, etc. Optical networking using wavelength-division multiplexing (WDM) is the technology of choice for meeting these demands [1,2]. There is consensus that successful and high-impact research in optical networking can be achieved by incorporating expertise from diverse disciplines, and referred to as "cross-layer design" [3-5]. In this regard, roughly three layers can be identified: (1) application layer at the top (including control and management software); (2) network architecture layer in the middle, and (3) physical (or optical communications) layer at the bottom (mapping with the three topics software, architecture, and hardware, respectively). This paper focuses on the middle layer (network architecture), while recognizing the importance of interworking with the application and physical layers. Section 1.1 discusses the major role software plays in optical networks, while Section 1.2 provides an overview of telecom networks. Section 2 outlines the promising R&D problems for optical networking in broadband access networks. Sections 3 outlines the R&D challenges for backbone optical networks.

1.1. Optical Networking: Role of Optics, Electronics, and Software

Figure 1 shows that the state of the art in optical science and engineering is in its infancy and has a lot of room for growth. This is in contrast with the state of the art in computer engineering (electronics) and software engineering, both of which are quite mature (and will continue to mature further). Note that Optical Networking System Proposition "A", which is based on disruptive optical technology (and hence is riskier) and which does not pay attention to mature electronics and software, would lead to a system with limited value.

Optical Networking System Proposition "B", on the other hand, is based on the philosophy that a technologist can create enormous system value by building a network which exploits the state-of-the-art optical devices, and supporting them with state-of the- art electronics and software. The technologist's intellectual property is created by determining how much of the art to employ in each from the three "pillars" – optics, electronics, and software – so that the solution is cost-effective, flexible, and scalable. Thus, instead of disruptive technology in the optical domain, one should think in terms of creating a disruptive integrated technology from all constituent domains of optics, electronics, and software. Finally, we remark that software that plays the most important role in providing intelligence and operational flexibility to our networks. The role of software in optical networks is tremendous.

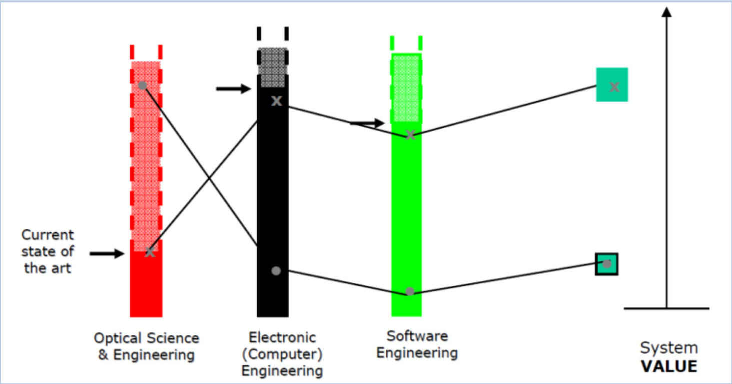

Figure 1
Optical networking system with three "pillars": system value proposition

1.2. Telecom Network Overview

Raghavendra et al.
Future optical networks: a review,
Indian Journal of Engineering, 2012, 1(1), 17-20,

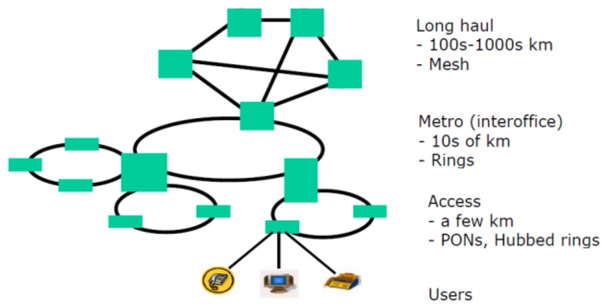

Figure 2
Telecom network overview

Figure 2 provides an overview of today's telecom networks. They consist of the access network, the metropolitan-area (or regional) network, and the backbone network. However, a popular school of thought is that the metro will get absorbed in access as the latter is expected to increase its reach over the next few years. The access network enables end-users – businesses and residential – 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 today for fiber-to-the-home (FTTH) standards). Current solutions for access are digital subscriber line (DSL) and cable modem. However, the access network continues to be a bottleneck, and users are demanding higher bandwidth. How to provide this high bandwidth in an inexpensive manner is a key R&D priority. Passive optical network (PON) is gaining momentum, especially the one based on inexpensive and ubiquitous Ethernet technology. The metro-area network typically spans a metropolitan region, covering distances of a few 10s to a few 100s of kilometers. Given the deep-rooted legacy of SONET ring networks in our networks, multi-wavelength versions of these rings have been deployed in metro networks. The backbone network spans long distances, e.g., each link could be a few 100s to a few 1000s of kilometers in length. The backbone network provides nationwide or global coverage. (For national networks covering smaller geographical areas, naturally, the link lengths will be shorter.) In telecom backbone networks, WDM fiber links are employed to connect the nodes which typically consist of optical cross connects (OXCs).

2. BROADBAND ACCESS

2.1. (Ethernet) Passive Optical Network (PON)

An access network should have high capacity, and it should be able to scale in terms of number of users and data rate; thus, optical technology is an attractive physical (Layer-1) medium for access networks. By employing passive optical components, an inexpensive transport mechanism can be created. These arguments lead to the Passive Optical Networks (PON) for building next-generation access networks. A PON uses a single trunk fiber that extends from a central office to a passive optical splitter, which then fans out to multiple optical drop fibers connected to access (i.e., subscriber) nodes. While various other flavors of PON exist (such as APON, BPON, GPON), Ethernet in the First Mile (EFM) is an attractive Layer-2 option for building the access network because of Ethernet's ubiquity and low cost. This gives rise to the Ethernet PON (EPON), which is designed to carry Ethernet frames at standard Ethernet rates. R&D and standardization activities on PONs are strong today. Efforts are underway for defining the 10-Gbps EPON standard (going beyond the 1- Gbps EPON which has been deployed). Also, while significant knowledge has been created on upstream traffic scheduling problems in PON, more research is needed on how to handle classes of service (including circuit emulation), quality of service, scalability, etc.

2.2. WDM in PONs

Although the PON provides higher bandwidth than traditional copper-based access networks, there exists the need for further increasing the bandwidth of the PON by employing WDM so that multiple wavelengths may be supported in either or both upstream and downstream directions. Such a PON is known as a WDM-PON. (Note that the standard PON operates in the "single-wavelength mode" where one wavelength is used for upstream transmission, and a separate one is used for downstream transmission.) Interestingly, architectures for WDM-PONs have been proposed as early as the late-1980s. However, these ideas have not yet met commercial success because of: lack of an available market requiring high bandwidth, immature device technologies, and a lack of suitable network protocols and software to support the architecture. A comprehensive review of WDMPON technologies – devices, architectures, and protocols – which have been proposed by the research community over the past several years can be found in [Ban05]. How to use WDM effectively in a PON so that the PON can become "data-burstness-aware" is an important problem for its commercial viability (instead of fixed bandwidth allocation using dedicated wavelengths to users as in a traditional WDM-PON).

2.3. Hybrid Wireless-Optical Broadband Access

2.3.1. Network (WOBAN)

The concept of a hybrid wireless-optical broadband access network (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 Central Office (CO); also, 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 towards 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. Please see [Sar07] for optimal placement of gateway nodes (where optical and wireless meet), routing and fault tolerance in WOBAN, etc.

2.4. Long-Reach Broadband Access

Advances in optical technology have led to more wavelengths to be multiplexed on a fiber, and each wavelength can support a high transmission rate, e.g., up to 40-100 Gbps soon. The geographical span of a PON is a linear distance of 10-20 km. However, the fiber capacity is much larger than the typical bandwidth needs of users served by such a PON. To serve more users, the reach of the PON can be extended to 100 km and beyond without incurring the complexity of traditional metro networks, i.e., keep the network architecture simple; and they are referred to as SuperPON in the literature. We refer to them as Long-Reach (LR) Broadband Access Networks because strictly speaking the network is not passive (and hence not a PON) any longer because it may need some simple (but few) active elements, e.g., optical amplifiers. Thus, many CO's can be consolidated, reducing the network's CapEx and OpEx. Some architecture for Long-Reach Broadband Access have been proposed; they focus on how to provide long reach access, high transmission rate, etc. But their tree-and-branch topology inherited from the basic PON architecture cannot provide good coverage to users in metro area (100 km), so alternate network architectures need to be developed which are more suitable for "two-dimensional" coverage.

2.5. Metro: The Vanishing Breed?

An Optical Add-Drop Multiplexer (OADM) is an important device for building optical metro networks. Multi-wavelength ring networks deployed today employ Fixed (or static) OADMs (FOADM) because the technology for FOADM is mature. However, Reconfigurable OADMs (ROADM) are more powerful than FOADMs, because a network architecture based on ROADMs can easily adapt to fluctuating traffic demands. Fortunately, ROADM technologies are becoming quite mature now, so appropriate network architectures and algorithms are needed to exploit the power of ROADMs. However, because the "reach" of the access network can be expanded significantly – to 100 km and beyond – it is expected that the long-reach access network will meet the backbone directly, so a natural question is: "will the metro network will become a vanishing breed?

3. BACKBONE NETWORKS

3.1. Dynamic Optical Circuit Switching (DOCS) ("Dial for Bandwidth")

With the emergence of bandwidth-hungry applications, backbone networks require high capacity and novel switching methods. Optical Circuit Switching (OCS) is quite mature today. However, end-users and various applications generate "bursty traffic," which the network should handle efficiently. Thus, OCS can benefit from more dynamism to handle bursty packet traffic. Hence, we need Dynamic Circuit Switching (DCS), whose optical implementation is called Dynamic Optical Circuit Switching (DOCS). DOCS can provide huge switching capacity to the edge packet applications. Therefore, it is a potential

Raghavendra et al.
Future optical networks: a review,
Indian Journal of Engineering, 2012, 1(1), 17-20,

solution for transporting packets over high-bandwidth circuits which are established dynamically over the telecom network backbone. There are many applications that need to reserve bandwidth on demand, ranging from scientific grid computing applications to consumer applications, e.g., video-on-demand (VoD), IPTV, etc. In today's data networks (e.g., IP network), two edge devices, e.g., interfaces of two IP routers, are interconnected by a leased line (namely a circuit of fixed bandwidth) with a long holding time, perhaps based on an annual lease. Using emerging optical networking architectures, particularly control-plane software and optical switches, such IP routers (and other edge devices) can "dial for bandwidth" on an as-needed basis. The holding time for such a "virtual" link between the edge devices can be of any duration: from a few seconds to months. Also, the capacity of such a bandwidth pipe can range from that of an optical wavelength channel (which is OC-192 (10 Gbps) or OC-768 (40 Gbps) today) to sub wavelength granularity. What architectural solutions should be developed to efficiently "groom" (i.e., pack, unpack, and switch at intermediate nodes) sub-wavelength granularity connections of diverse bandwidth (including IP flows, multi-protocol label switching (MPLS) tunnels, etc.) on to high-capacity wavelength channels in an optical network? How can DOCS technologies be used to create Lambda Grids for various e-science and other applications?

3.2. Robust Network Design

With the maturing of WDM technology, a single fiber link can carry a huge amount of data, which might be on the order of terabits per second. However, the failure of a network component (e.g., a fiber link, an OXC, an amplifier, a transceiver, etc.) can lead to a huge loss in data and revenue. To facilitate robust network design, both proactive and reactive methods are needed, where proactive methods pre-plan some of the recovery methods in advance such as setting aside backup routes, sharing backup capacity with other paths' backup capacity, setting up backup routes only (but not necessarily backup bandwidth), etc. Noting that different users may have different needs, and also that different parts of a network may have different failure characteristics, differentiated survivability methods need investigation. Traditionally, the notion of network service has been "binary", i.e., it is either available (as contracted) or not. But the notion of "degraded service" is being developed, i.e., even if some parts of the network are down, service can still be provided at a reduced level, if possible. How to deal with large-scale network disasters need be developed so that, again, if some parts of the network are working, they should be able to support as much of the services as possible. Research on large-scale correlated failures (or attacks) is needed. The correlation between survivable network architectures and network security needs be studied.

3.3. Ethernet Everywhere

Being the dominating LAN technology, around 90% of Internet traffic is generated by end systems with Ethernet interfaces. Hence, efforts for extending Ethernet usage beyond LANs to the backbone are in progress [Kir06, Bat07]. The future mode of operation is to carry native Ethernet frames directly over WDM optical backbone networks (Ethernetover- WDM). Thus, several layers of other technologies can be eliminated, and significant savings in Capital Expenditures (CapEx) and Operational Expenditures (OpEx) can be achieved. In a backbone network, Ethernet can be set up as a connection-oriented service with tunnels carrying Ethernet frames. What are the appropriate forwarding technologies for such tunnels, e.g., Virtual-LAN Crossconnect (VLAN-XC), Provider Backbone Transport (PBT), and Transport Multi-protocol Label Switching (T-MPLS)? If Ethernet-over-WDM is present inside the carrier's backbone (carrier-grade) network, Ethernet will now require carrier-level reliability. Eventually, the concept of end-to-end Ethernet spanning access and backbone is not that farfetched, so the corresponding architectural issues need to be studied.

3.4. Other Research Topics

For longer-term research, we consider the following topics to be appropriate [Muk06]: (a) Network architectures and algorithms to combat optical signal-quality impairments, (b) Optical multicasting using "light-trees", and (c) Optical packet switching (OPS) / optical burst switching (OBS).

4. EMERGENCE OF AN ALTERNATIVE NETWORK MODEL

Following the realization that a computer bus speed cannot match a lambda-based optical network (at 10 Gb/s), it was suggested that it should be possible to create a tightly integrated cluster of computational, storage, visualization, and instrumentation resources linked over parallel dedicated optical networks across campus, metro, national, and international scales to support scientific tasks, and this concept is now being demonstrate d in network test beds and NRENs. Scientific and grid applications have complex workflows, which will make extensive use of an optical network, for example, to transfer huge amounts of data between storage and computing or visualization resources. In many ways, NRENs mirror the possible future requirements on telecommunication networks and may evolve to use a similar set of optical technologies (e.g., OBS). NRENs have high-speed optical backbones and can already offer dedicated channels (wavelengths) to individual research users. Switching within these networks is, at present, generally achieved through OEO switches, allowing wavelength routing. NRENs are seen as an important vehicle for advancing innovation and discovery and as a platform for undertaking network research. In Europe, GEANT connects 30 such NRENs (with bit rates up to 10 Gb/s); in Japan, JGN2 provides an research and development environment (at 10 Gb/s); Abiline in the United States interconnects 50 states; Canada has CA∗,net; and China's CERNET2 connects 20 cities (at 10 Gb/s). Global Lambda Integrated Facility (GLIF) [30] is an international virtual organisation whose members are NRENs and promotes lambda networking for international collaboration and research. In today's NRENs, resources are provided either exclusively for an application or are shared on a best-effort base. Many emerging applications demonstrate a dynamic nature and require connectivity, bandwidth, or QoS that may change with time and/or user profile. The administrative and technical overhead to provide such network services and the high associated costs currently inhibit a wider commercial adoption of such demanding applications. A short- to medium-term solution to the above requirements is the ability to negotiate flexible service level agreements between the application and the resource provided. This is a subject of current research and standardization within the Global Grid Forum.

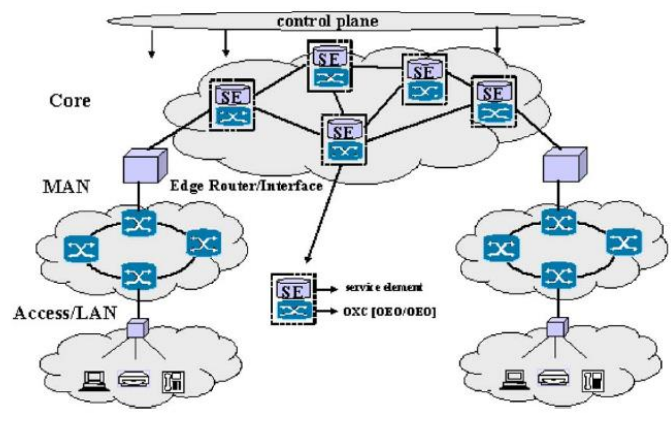

Figure 3
Schematic of telecommunications network

As a longer-term solution, a new network service model that allows users or/and applications to adapt the network to their applications is discussed here. This network model will require the network topology to migrate from the traditional edge-core telecom model (Fig. 3) to a more distributed model. In this type of network, the user may have the ability to control routing in an end-to-end manner and set up and tear-down lightpaths between routing domains. To facilitate this level of user control, users or applications will be offered management/control of the network resources (i.e., bandwidth allocation at the wavelength and sub wavelength level). These resources could be leased and exchanged between users. Such new topological solutions will have a direct impact on network management and control as well as the network infrastructure, including network elements and user interfaces to enable and support these functionalities.

An important step toward this is the ability to make dynamic resource reservations immediately when needed or in advance for a time period in the future. Dynamic optical networking can satisfy the bandwidth and reconfiguration requirements of this model together with software tools and frameworks for end-to-end on-demand provisioning of network services across multiple administrative and network technology domains. Fig. 4 illustrates the global interconnection of a number of NRENs using interconnecting networks such as GEANT or GLIF. Within each network, the choice of switching technology and transport format is an important consideration that influences the ability to deliver NG network services. As discussed above, optical switching offers

Raghavendra et al.
Future optical networks: a review,
Indian Journal of Engineering, 2012, 1(1), 17-20,

bandwidth manipulation at the wavelength and sub wavelength level (e.g., with optical circuit/burst/packet switching) as well as the capability to accommodate a wide variety of traffic characteristics and distributions.

The transport format determines how signaling and control messages as well as data are sent from the user/client to the optical network and depends on the form of switching. Thus, for 1) circuit switching, signaling is sent in conjunction with the data or over a dedicated wavelength or SDH/SONET connection, and for 2) OBS/OPS, signaling is sent using a signaling packet or control burst; hybrid approaches can also be used. The service model proposed here does not depend on transport technology (i.e., CS, OBS, OPS). Actually, the first implementation will address wavelength-switched optical infrastructures. However, sub wavelength granularity will enable the offering of dynamic network services to a wider range of users and applications. The choice of transport format is mainly driven by an understanding of the traffic characteristics generated by users and their applications. For example, wavelength switching may be the preferred solution for moving terabytes of data from A to B but is inappropriate for video games applications. The diagram also shows other important elements of this global network. Each NREN has an associated network resources provisioning system (NRPS) currently being developed and deployed around the world by different international organizations. These systems are based on the abstraction of network resources. For instance, the user-controlled light path provisioning system (UCLP) can be thought of as a configuration and partition manager that exposes each light path in a physical network and each network element associated with a Light path as an "object" or "service" that can be put under the control of different network users to create their own IP network topologies. UCLP, as proposed by CANARIE, is an NRPS that deals with the abstraction of network resources as objects to allow end users to manage them in order to build reconfigurable discipline or application-specific networks. More specifically, UCLP is a set of distributed services that are used to establish and tear down end-to-end connections across an optical network. The service plane mainly involves application-level middleware and Application Programming Interfaces (APIs). The service middleware in this architecture will provide a unified application execution environment relying on a high-bandwidth QoS-enabled network infrastructure of global scale. The middleware could implement service abstractions exposing network resources (end-to-end QoS management). Hence, it will be possible for an application to request network constraints (e.g., guaranteed bandwidth or latency among computational nodes).

5. CONCLUSION

The road ahead for research and development in optical networks is an attractive one. Exciting topics include incorporating WDM in PONs, hybrid optical wireless access, long-reach broadband access, dynamic optical circuit switching, robust network design, Ethernet everywhere, etc.

REFERENCES

1. B. Mukherjee, *Optical WDM Networks*, Springer, 2006.
2. B. Mukherjee, F. Neri, et al., "Report of US/EU Workshop on Key Issues and Grand Challenges in Optical Networking," June2005. (http://networks.cs.ucdavis.edu/~mukherje/USEU- wksp-June05.html)
3. A Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, G. Kramer, K. Kim, and B. Mukherjee, "Wavelength-Division Multiplexed Passive Optical Network (WDM-PON) Technologies for Broadband Access: A Review [Invited]," *OSA Journal of Optical Networking (JON)*, vol. 4, no. 11, pp. 737-758, Nov. 2005.
4. S. Sarkar, S. Dixit, and B. Mukherjee, "Hybrid Wireless-Optical Broadband Access Network (WOBAN): A Review of Relevant Challenges," *IEEE/OSA Journal of Lightwave Technol.*, Nov. 07, to appear. (Invited Paper)
5. Kirstädter, C. Gruber, J. Riedl, and T. Bauschert, "Carrier-grade Ethernet for Packet Core Networks," *Proc., SPIE*, vol. 6354, 2006. [Bat07] M. Batayneh, D. A. Schupke, M. Hoffmann, A. Kirstädter, and B. Mukherjee, "On Reliable and Cost-Efficient Design of Carrier-Grade Ethernet in a Multi-Line Rate Network under Transmission-Range Constraints," *Post- Deadline Paper, OFC'07,* March 2007.

AUTHOR PROFILE

Dr. M.V.Raghavendra is currently working as Associate Professor, Electrical Engineering Dept, Adama Science & Technology University, Ethiopia. He received his PhD from Singhania University, Rajasthan, India in the field of Optical Communication and he is a Research scholar, Department of Instrument Technology, College of Engineering, Andhra University Vishakhapatnam, Andhra Pradesh, India. He has received his M.Tech Degree from ECE Dept, College of Engineering, Andhra University. His main research includes signal estimation & evaluation of optical communication, Satellite communication & Microwaves. He has published papers in reputed national & international Journals. He has participated in different national & international conferences. He is a life member of ISTE & ISOI, MIAENG, MIACSIT, and MAIRCC.

Mr. G Subba Rao is currently working as Associate Professor, Electrical Engineering Dept, Adama Science & Technology University, Ethiopia. He received his M.Tech from SRM University, Chennai, India. His research interest is Wireless & Mobile Communication.

Mr. V.Sudheer Raja is Currently working as assistant professor in Adama science and technology university, Ethiopia, he received his M.Tech(2009)-JNTU Hyderabad-Digital systems and computer electronics, his area of interest is Vlsi design and Digital design

Raghavendra et al.
Future optical networks: a review,
Indian Journal of Engineering, 2012, 1(1), 17-20,