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Review of Optical World Technologies and Switching Network Devices

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Abstract- **Optics is the science of light and has a very long history. In the modern world of telecommunication and information and communication technologies (ICT), the term "photonics" is sometimes used for the application of optical technology, such as lasers and optical fiber, in electronics.In the past, high costs have prevented optical components from finding their way into computers. But as optical technology matures, prices drop and the limits of miniaturization appear to have been reached, the computer industry is re-evaluating the situation and incorporating optical alternatives into computer systems. The use of all types of optical equipment in communication networks and computers, because they consume less power, is seen as a major saving on operational costs for service providers, while at the same time helping to reduce the carbon footprint of telecommunication. The gradual incorporation of optical technology into the world of traditional electronics is paving the way for the era of the optical world.**

.***Keywords*—** **Bus, Bandwidth, Optical fiber, Optical network, Switching Network**

I. INTRODUCTION

Today, the most widely used optical technology is optical fiber for high-speed interconnections, such as in server racks, connecting offices, buildings, metropolitan networks, and even continents via submarine cables. Optical technology is also employed in CD-ROM drives, laser printers, and most photocopiers and scanners. However, none of these devices is fully optical all rely to some extent on conventional electronic circuits and components. The above-mentioned technologies represent entry paths for optical components into other areas of the ICT universe.

This report will focus primarily on the use of optical technology in data communication devices, and this is what is referred to whenever the term "optical computing" is used. The term "photonics" is taken to cover all applications of light technology, from the ultraviolet part of the spectrum, through the visible, to the near-, mid- and far-infrared (See Figure 1).Photonics is increasingly being used in data communication because it provides more ultra-high-capacity and speed in storage, communication and computation. Without optical technologies and optical networking related standards, the Internet as we know it today would not be feasible. Optical technologies have been the driving force behind the bandwidth growth of the Internet and enabled the emergence of band-width hungry applications for video and new business models such as YouTube which allows users to share video clips. ITU-T standards in optical transport networks have played an leading role in transforming the Internet's bandwidth capabilities. This work is led by ITU-T Study Group 15, which has developed a set of international standards (or Recommendations) that defines the existing optical transport network (OTN) framework, and is currently developing future technologies such as gigabit capable and 10-gigabit-capable passive optical networks (GPON and XGPON) to satisfy the unprecedented bandwidth requirements that will soon be demanded by service providers and consumers. This report surveys the developments and challenges ahead for optical communication and computing, and identifies optical related standardization activities.

II. WHY OPTICAL TECHNOLOGY?

Optical technology is viewed by industry experts as the most feasible means of solving the bandwidth limitation of electronics. It has the ability to deliver higher speeds that can enhance processing power and data transmission rate compared to current silicon chips – and all while consuming less power.

III. OPTICAL COMMUNICATION AND NETWORK DEVICES

In this report, optical communication is used taken to mean devices that transmit data by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized the telecommunication industry and have played a major role in the advent of the information age. Because of its advantages over electrical transmission, optical fiber is rapidly replacing copper wire in core networks in the developed world and is key for developing countries in bridging the digital divide.

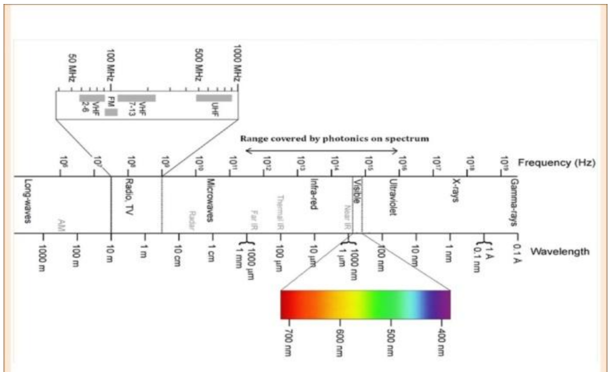

Figure1: frequency spectrum

Traditionally, optical devices include items such as polarizer's, wave plates, reflectors, filters, and lenses. However, when we consider the concept of communication in optical devices, the scope widens to encompass beam-splitters, phototransistors, laser diodes and more, including:

- light emitters and receivers;
- linear image sensors;
- optoelectronic devices; and
- Photo detectors.

The main advantages of using optical technologies in communication systems are that the high frequency of the optical carrier enables significantly more information to be transmitted over a single channel than is possible with a conventional radio or microwave system. Optical components are much smaller and lighter, with the additional benefit of consuming less power. Since energy conservation is gaining

increasing interest nowadays, the energy-saving characteristics of optical technologies represent huge opportunities for reducing the carbon footprint of ICTs.

The communication process using optical fiber involves the following basic steps (shown in Figure 2):

- creating and encoding the optical signal involves the use of a transmitter – lasers and light-emitting diodes (LEDs) are generally used for this purpose;
- transmitting the signal along the fiber;
- ensuring that the signal does not become too distorted or weak, hence the use of amplifiers; and
- Receiving the optical signal and converting it into an electrical signal using an optical receiver.

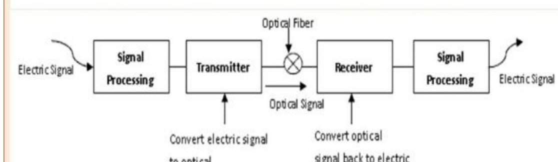

Figure 2: Basic steps in optical communication

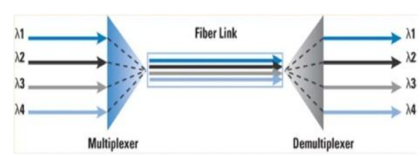

Figure 3:wavelength division multiplexing (WDM), functional model

Wavelength division multiplexing (WDM) can optimize the potential high bandwidth of optical fibers by enabling several distinct data signals to share a single fiber, provided that they have different wavelengths. Multiple wavelengths are therefore multiplexed into a single optical fibre and multiple light-path data are transmitted [1] (See Figure 3).

Current communication networks using optical fiber still need to convert the electrical signal into an optical one for transmission, and then back into electrical form at the receiving end. Thus, the potential bandwidth of optical fibers is not being fully exploited. Therefore, future research and standardization work will be focused on developing purely optical devices for communication networks.

III. STANDARDIZATION ACTIVITIES

This section mainly looks at current and future standardization activities in the following areas:

1. optical transport network;
2. optical switching and optical cross-connect;
3. automated switching optical network architecture;
4. passive optical network;
5. optical Internet exchange;
6. visible light communication;
7. optical data transfer inside the computer; and
8. All-optical computer.

IV. OPTICAL TRANSPORT NETWORK (OTN)

Synchronous optical networking (SONET) was adopted as the backbone of most fiber-optic telecommunication networks in the late 1990s. SONET was originally designed for optical interfaces that used a single wavelength per fiber. As fiber-optic technology has advanced, it has become more economical to transmit multiple SONET signals over the same fiber using WDM instead of going to a higher rate SONET signal. In 2003, ITU-T Study Group 15 defined a transport network that was optimized for cost-effective transparent transport of a variety of client signals over WDM networks. The optical transport network (OTN) architecture is specified in Recommendation ITU-T G.872 and the frame format and payload mappings are specified in Recommendation ITU-T G.709 for carrying SONET, Ethernet and storage area network (SAN) signals in a much more cost-effective manner than was possible over SONET networks.

Using OTN, multiple networks and services such as legacy SONET, Ethernet, storage protocols and video can all be combined onto a common infrastructure. Most importantly, unlike SONET, OTN is the only transport layer in the industry that can carry a full 10/40/100 Gbit/s Ethernet signal from IP/Ethernet switches and routers at full bandwidth. With the rapid migration to IP/Ethernet-based infrastructure, OTN becomes the transport layer of choice for network operators.OTN is composed of a set of optical network elements connected by optical fiber links. It is able to provide functionality of transport, multiplexing, routing, management, supervision and survivability of optical channels carrying client signals.[1] The OTN framework is based on a set of Recommendations with ITU-T G.709 at the heart. An OTN is sometimes also referred to as an all-optical network (AON), where optical connections known as light paths are used for data transmission.[2]Recommendation ITU-T G.709 "*Interfaces for the Optical Transport Network (OTN)*" describes a means of communicating data over an optical network, as well as requirements in the areas of optical transport hierarchy (OTH), functionality of the overhead in support of multi-wavelength optical networks, frame structures, bit rates and formats for mapping client signals. It is a standardized method for transparent transport of services over optical wavelengths in dense wavelength division multiplexing (DWDM) systems.

V. OPTICAL SWITCHING AND OPTICAL CROSS-CONNECT

In order to implement the all-optical network, a number of optical devices are required. Two of them are optical switches and optical cross-connects, which are very important in enabling a truly optical backbone. In an optical switch, both the input/output (I/O) modules and the backplane are optical. An optical switch enables signals in optical fibers to be selectively switched from one optical circuit to another. These switch-es use the concept of combining optical add/drop multiplexing and optical cross-connect between two main transmission lines in order to implement the wavelength routing operation.

An optical cross-connect (OXC) is used by telecommunication carriers to switch high-speed optical signals in a fibre-optic network. Core optical networks consist of OXCs and fiber links interconnecting OXCs. Examples of OXCs include optical add drop multiplexers (OADM), photonics cross-connects (PXC), and reconfigurable optical add/drop multiplexers (ROADM). Each OXC can route an input wavelength to an output wavelength. Thus, an optical connection can be established between edge nodes.

ROADMs are being implemented to provide automated provisioning in modern multichannel fiber-optic networks. They reduce costs, speed up provisioning time, and eliminate human error from manual recon-figuration. Essentially, this type of multiplexer has the ability to control the direction and focus of both infra-red and visible light emissions within a range of different wavelengths. The technology of ROADM makes it unnecessary to convert these emissions into electrical signals that must be converted back into their original form at the point of termination.[5]

The primary benefit of all-optical devices may be their greater scalability compared with optical-electrical-optical (OEO) ones. In an OEO switch, the I/O modules are optical, but receivers convert photons into electrons for their journey over the electronic backplane. At the output module, the electrons are converted back into photons.

All future optical switch and OXC designs, however, are focused on AONs, where the user's data travel entirely in the optical domain.

VI. AUTOMATICALLY SWITCHED OPTICAL NETWORK (ASON) ARCHITECTURE

According to the annual Cisco Visual Networking Index[6], the estimated global Internet Protocol (IP) traffic was estimated at 176 exabytes ($x10^{18}$) in 2009 and is projected to increase more than fourfold to reach 767 exabytes by 2014. This growth will be driven mainly by video, due to improvements in bandwidth capacity and the increasing popularity of high-definition and 3D television.

Backbone networks must preserve quality of service amidst this ever-expanding growth of broadband In-ternet traffic and bandwidth-hungry IP devices and applications. In view of this, the need for network flexibility for AONs has given rise to the emergence of the automatically switched optical network (ASON). Its purpose is to automate resource and connection management within the network to preserve quality of service.

Therefore, future optical backbone networks should be capable of:

- controlling and managing multiple layers;
- coping with unexpected situations quickly;
- applying the operator policies;
- providing rate- and format-free flexibility; and
- providing on-demand services.

The main issue in the area of standardization for ASON has been the optical control plane. Optical control plane standards can provide two benefits:

- automated optical networks can be built with devices from a mixture of vendors;
- all devices will need to conform to a set of minimum requirements to ensure interoperability.

VII. PASSIVE OPTICAL NETWORK (PON)

A passive optical network (PON) extends from an operator's central facility into individual homes, apartment buildings and businesses. PONs can be deployed in a fiber-to-the-home (FTTH) architecture or in fiber-to-the-building (FTTB), fiber-to-the-curb (FTTC) or fiber-to-the-cabinet (FTTCab) architecture, depending on local demands.[7]

ITU-T Technology Watch In order to reduce the need for separate fibers for the two directions of transmission, PON systems can take advantage of the WDM signal multiplexing technique, where downstream and upstream channels are transmitted at different wavelengths. Compared with point-to-point architectures, a PON configuration reduces the required amount of fiber and equipment at the central facility. The traffic is encrypted to prevent eaves dropping. One common application of PON has been in providing broadband Internet access to homes for applications such as IP television (IPTV), where it is a serious competitor with digital subscriber line (DSL) technology. FTTH allows for much greater bandwidth, which is essential for broadband triple-play services. However, it also requires the installation of new transmission, wiring and receiving infrastructure.

PONs use passive optical components such as optical fibers, directional couplers, star couplers, splitters, passive routers and filters. Since PONs are used for communication over short distances, usually less than 60 km, optical signals do not require amplification.

VIII. OPTICAL EXCHANGE

Peering of regular Internet traffic has led to switching-based Internet exchanges [2]. Optical exchanges on the other hand will not require switching technology at peering locations. With the fall in cost of optical de-vices, they could become viable as components in Internet exchange points. An optical exchange is a peering location that allows traffic to pass from one provider to another in a connection-oriented manner [2].

An example is NetherLight[8] in Amsterdam, which is based on SONET/SDH cross-connect and gigabit Ether-net switching facilities for high performance access to connected networks (see Figure 4).

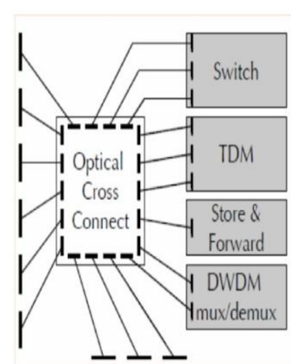

Figure 4: Schematic diagram of an optical exchange

The Nether Light Exchange Point is part of the Global Lambda Integrated Facility (GLIF) network. GLIF is an international organization that promotes optical networking using lambda switching, which can switch individual wavelengths of light onto separate paths for specific routing of information. The GLIF network is based around a number of lambda networks contributed by GLIF participants who own or lease them. The-se are interconnected through a series of exchange points known as GOLEs (GLIF Open Light path Exchanges). GLIF takes advantage of the cost and capacity advantages of optical multiplexing, in order to build powerful distributed systems at various sites around the globe.[9] GLIF uses optical multiplexing capabilities to provide the bandwidth needed for scientific research and collaboration on a global scale. Some sites which form part of the GLIF network are CERN Light (Geneva), UK Light (London), Moscow Light (Moscow), Star Light (Chi-cago) and TaiwanLight (Taipei).

IX. VISIBLE LIGHT COMMUNICATION (VLC)

White light-emitting diodes (LEDs) are well known for their energy saving properties and long life. However, white LEDs also have the potential of being used as an indoor optical wireless broadband communication system. VLC using LEDs is emerging as a key technology for ubiquitous communication systems, because LEDs have the advantages of fast switching, long life expectancy, relatively low cost, and safety for the human body. This is an emerging area of research that is attracting attention.

Currently, Wi-Fi is the technology which is used in most wireless networks in homes and businesses. Wi-Fi is a radio frequency-based technology and its bandwidth is limited. On the other hand, visible-frequency wire-less does not have the bandwidth limitation problem. The signal would be generated in a room by slightly flickering all the lights in unison. People would not notice this, because the rate of modulation would be millions of times faster than a human eye can see. Since visible light cannot penetrate walls like radio, there would be no interference from stray signals and reduced opportunity for outside hackers, thus making the system more secure. In January 2010, Siemens researchers, in collaboration with the Heinrich Hertz Institute in Berlin, achieved a wireless data transfer rate of up to 500 Mbit/s using white LED light.[11]

Research has shown that infrared light could also be used in visible light communication. The Infrared Data Association (IrDA) has been developing technical standards for infrared wireless communication and has recently announced the GigaIR standard for very short range line-of-sight infrared communication links operating at 1 Gbit/s. Speeds of more than 1 Gbit/s have been obtained with infrared light, according to re-search carried out by Penn State University.[12]

X. OPTICAL DATA TRANSFER INSIDE THE COMPUTER

So far, optical technology has been confined mostly to telecommunication networks and the cabling in data centers. However, progress in computer technology is becoming heavily reliant on ultra-fast data transfer between and within microchips. This is an emerging area of technology in which optical interconnects are being applied.

I. THUNDERBOLT

New data transfer technology based on optical fibers will lead to dramatic advances in the performance and design of computers. An example is Thunderbolt (originally codenamed Light Peak), a technology that has been developed by Intel to give ordinary personal computers the ability to connect with other devices using high-speed fiber-optic cables at 10 Gbit/s – twenty times faster than a standard, copper-based USB 2.0 cable [6]. This means the cable could drive a high-definition (HD) display or transfer an HD movie in seconds.

Thunderbolt technology enables engineers to [6]:

- Design standalone performance expansion technologies commonly used in desktops and workstations, using existing native device drivers and interconnected by a single cable.
- Introduce thinner and lighter laptops, expandable through Thunderbolt technology and its miniature connector designed for mobile applications, without sacrificing I/O performance.

II. SILICON PHOTONICS

At present, the use of multi-core central processing units (CPUs) is expanding as one way of controlling power consumption while maintaining the trend toward high-performance electronic circuits. In a multi-core scheme, a large number of signals must be transmitted at high speed, but when metallic wiring is used, limitations arise due to signal delays and increases in power consumption. To overcome these limitations, researchers are investigating optical interconnection technology for the CPU based on wavelength division multiplexing by applying miniaturization and optical/electronic integration.

Silicon photonics [7] is an emerging area, and involves integrating optical and electronic circuits on silicon. It is one area of research that promises to produce optoelectronic devices in large numbers. The low cost of silicon and its high availability make it the material of choice for optoelectronic devices. It presents tremendous opportunities for both optical communication and for data transfer in computers in the future. Silicon photonics can be applied in optical interconnects and in optical routers.

III. OPTICAL BUS

Similarly, IBM announced in 2010 that it has successfully developed an optical data bus on a printed circuit board that uses optical links for data transfer between the processor and other external components such as memory and input/output ports. By avoiding the signal-loss and crosstalk problems associated with copper, an optical bus would make supercomputers much faster. IBM is planning to use the optical bus in supercomputers for optical data transfer between printed circuit boards.

CONCLUSION

As has been outlined in this report, the main areas for future work on optical communication can be summarized as follows. Evolution of bandwidth capability of optical network components to achieve terabit speeds. Standards for all-optical devices such as DWDM multiplexers, ADM and OXC, which are essential components of an intelligent all-optical core router for the Internet where packets are routed through the network without leaving the optical domain. Security schemes to protect against attacks targeting all-optical devices in a fully optical communication system or computer. Visible Light communication systems for indoor networks and global location positioning. New ways for packaging optical devices to standardize the development of an all-optical transistor that can be mass-produced. Standardization work in ITU is already well engaged on the evolution towards an all optical core network for Internet and other telecommunications services. In order to provide more visibility to the work being done in field of optical networking in ITU it is suggested that a workshop be held with the objective of showcasing the developments made and future evolution of the optical network. The all-optical network could be the focus of a future Technology Watch Report where the standardization work in the field of optical networking could be investigated. The potential applications for visible light communication systems could also be investigated further.

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