DWDM And The Future Integrated Services Networks

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Abstract

This article provides an overview of the DWDM network and its current technologies. A discussion on DWDM applications and the system requirements, as well as the roles of current network architectures, such as the SONET, ATM and TCP/IP, in the DWDM framework is presented after the overview. An analysis of system requirements for the full optical DWDM integrated services network is then provided.

Sommaire

Cet article fournit un aperçu sur les réseaux de DWDM et de ses technologies actuelles. Une discussion suivra sur les applications de DWDM et les besoins de système, ainsi que le rôle des architectures de réseau actuelles, telles que le SONET, ATM et TCP/IP, dans le cadre de DWDM. Une analyse sur les besoins de système de services intégrés de réseau DWDM entièrement optique sera ensuite présentée.

1.0 Introduction

It is no doubt that the future of the communication network lies on the integrated services given the bandwidth capacity of a single fiber. The competition for the integrated services network has been among three forces, the ATM-based broadband integrated services digital network (B-ISDN), the cable TV, and the Quality of Service (QoS) enabled Internet. Among these three candidates, the B-ISDN has been the most mature and complete system. The QoS enabled Internet is still in its early research stage. The cable TV network has been focused on the access-network level rather than on a global communication network. With its primary success, in terms of point-to-point bandwidth, the Dense Wavelength Division Multiplexing (DWDM) network is reshaping the landscape of the communication networks. All of the above mentioned three types of communication networks plus the circuit switching SONET will unlikely be the framework of the future communication network. Instead, they will have to reposition themselves in order to find a role in the DWDM infrastructure. Given the bandwidth capacity in each channel of the DWDM network, the future of the DWDM also lies on integrated services. To achieve this, a time domain multiplexing (TDM) scheme, e.g., circuit switched SONET or cell switched ATM, is required in each channel and among the channels. The questions that arise are which TDM is the best candidate for this and how can they be implemented. This article provides an overview on the status of DWDM technology. Analyses on the future roles of existent TDM network protocols in the DWDM network and the future DWDM based integrated services are also discussed.

2.0 DWDM Networks

2.1 The Principle and Architecture of DWDM

Wavelength division multiplexing operates by sending multiple light waves (frequencies) across a single optical fiber. Information is carried by each wavelength, which is called a channel, through either intensity (or amplitude) or phase modulation. At the receiving end, an optical prism or a similar device is used to separate the frequencies, and information carried by each channel is extracted separately. Binary digital signal, which is a full on/off intensity modulation, can also be carried by each individual channel, although the bit rate is expected to be lower than the intensity or phase modulation. As in conventional frequency division multiplexing (FDM) used in electrical signal or radio wave transmissions, the carriers can be mixed onto a single medium because light at a given frequency does not interfere with light at another frequency within the linear order of approximation.

The basic principle of optical communication, including DWDM, is depicted in Figure 1, in which the transmitter modulates the input signal using amplitude (or intensity)-shift keying (ASK), frequency-shift keying (FSK), or phase-shift keying (PSK) to a carrier lightwave at frequency Fs with a very narrow frequency linewidth - a single frequency laser (or a single color light). This modulated signal, which combines with other signals of different frequencies, is transmitted along the optical fiber to the receiver. The signal is then converted back to the electrical signal by way of an optical detector and a demodulator. Switches or routers of some kind may also be involved between the transmitter and the receiver.

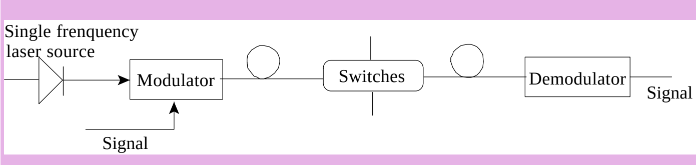

Figure 1: Principle of optical communications

Figure 2 depicts the basic architecture and operations of DWDM networks, which consists of end nodes, switch nodes, and optical fiber links. The end nodes consist of modulators/demodulators (or modems) for every channel, and multiplexers and demultiplexers for combining or separating the lights of different frequencies. The modulators encode digital data into waveform symbols through either an intensity or a phase modulation method, and the demodulator reverses the process to obtain digital data. The switch nodes consist of add/drop multiplexers and demultiplexers, wavelength switches, and wavelength converters. The multiplexers are used to combine the signals of different wavelengths for transmission and the demultiplexers are used to separate the signals of different wavelengths for switching. The wavelength switch cross connects the input channels to the desired output channels. The function of the wavelength converters is to convert the over-demanded wavelengths to free wavelengths in a given fiber to achieve high channel utilization.

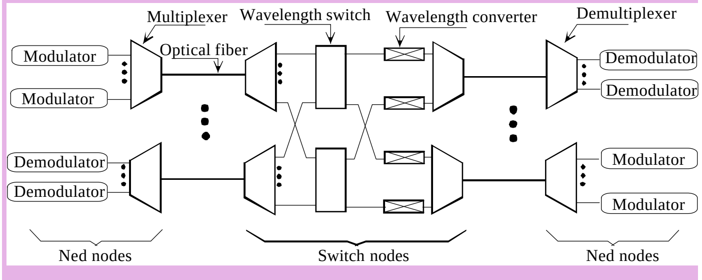

Figure 2: Major components of a DWDM network

2.2 Modulators/Demodulators

The most efficient way to modulate and demodulate the signals is to use semiconductor lasers. Modulating the drive current of a semiconductor laser can produce either frequency/intensity modulation depending on the configuration of the semiconductor modulator. A simple form of phase modulator can be made by passing the light along a strip waveguide formed in an electro-optic material such as lithium niobate, LiNbO3 (Figure 3). Application of the modulating voltage waveform to the electrodes causes a variation of the phase length of the channel. External amplification may be required for this form of modulator.

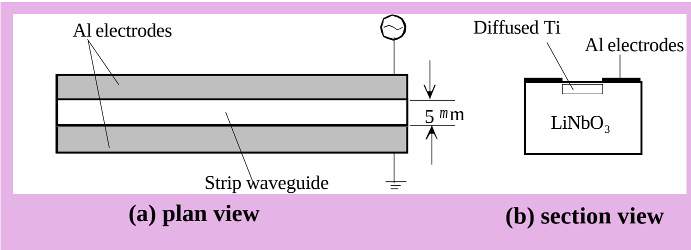

Figure 3: Example of a lithium niobate strip waveguide phase modulator: (a) plan view; (b) section

An amplitude (or intensity) modulator can be constructed by a Mach-Zehnder interferometer. This, too, can be a waveguide in an electro-optic material, as shown in the schematic plan view of Figure 4. The modulating voltage now causes a variation of the relative phase difference between the two paths. At the output waveguide the two waves recombine as the sum of the two modes: the fundamental mode which is guided and a higher-order mode which is unguided and radiated away. As the path difference varies, the proportion of the power in each mode changes and the guided output power is modulated.

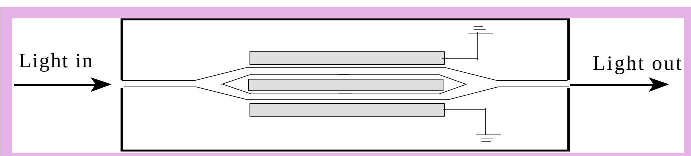

Figure 4: A schematic plan view of a lithium niobate diffused strip waveguide Mach-Zehnder interferometer modulator

A passive Mach-Zehnder interferometer can be used to convert frequency modulation to intensity modulation. Also, a full on/off intensity (or pulse waveform) modulation can be achieved with a reduced amplitude of the modulating current. A system of this kind has been demonstrated in a field trial over an underwater link of 132 km of standard single-mode fiber back to early 90's. Using the interferometer, the required intensity modulation at 1.12 GHz was obtained with an input frequency deviation of 5 GHz (0.04nm) and the link was not dispersion limited. The chirp that would have resulted from direct intensity modulation of the laser at this frequency was nearer to 60 GHz (0.5 nm). With a fiber dispersion coefficient of 15 ps/(km.nm), this would have given rise to a r.m.s. dispersion width of about 1 ns over the 132 km and so would have limited the bit rate to some 250 Mb/s.

Multiplexers/demultiplexers, which are used to combine/separate wavelength channels, are also important components in DWDM networks. The mechanisms have long been well understood, and devices of different types have also been constructed in the optical field. Key technologies underpinning current commercial DWDM Multiplexers/demultiplexers include thin film interference filters, fiber Bragg gratings (FBG), cascaded waveguide- or fiber-based Mach-Zehnder interferometers, bulk diffraction gratings, arrayed waveguide grating, and hybrid combinations of such technologies.

So far, the realization of modulators /demodulators based on the above methods, and multiplexers/demultiplers have been successful, which makes a point-to-point DWDM network possible. Commercial products of modulators /demodulators and multiplexers/demultiplers are generally available. DWDM networks for point-to-point transmission have been deployed by several telecommunication companies, including Nortel networks. In the meantime, the number of channels and the bit rate per channel have been rising exponentially. An 80-channel 50-GHz channel spacing multiplexer/demultiplexer has been reported by JDS Uniphase, an Ottawa based optical communication device company, based on an enhanced interleaving technology[1]. Nortel Networks demonstrated its 6.4 Tbps platform, which is considered as the highest bit rate up to date, at TELECOM'99 in Geneva in December 1999[2].

2.3 DWDM Switching/Routing

A simple routing function proposed to add to the point-to-point DWDM network is the broadcast-and-select routing in which each user on the network transmits its signal into a broadcast star coupler which was used to distribute those signals passively to all other nodes on the network. A media-access protocol is required to control the transmissions of the various network nodes to avoid collisions and to manage contention for the network bandwidth. The potential attractions of this type of network are its simplicity and performance, since no switches or routers are involved. The principle limitation of this network is that it is not scalable to large number of nodes because there is a linear relationship between the number of nodes and the number of wavelengths. Work in this area is still underway for interconnection of computers in local and metropolitan area networks. Application to large-scale networks is however not feasible due to the lack of graceful scaling [3].

Wavelength routing will be the first step of routing ability for DWDM, which is currently in research stage. Wavelength routing is defined to be the selective routing of optical signals according to their wavelengths as they travel through the network elements between source and destination. There are two salient features of wavelength routing. First, wavelength routing determines the path taken by the optical signal, and if multiple signals are launched from a given node, each may go to a separate distinct destination. The number of such destinations is equal to the number of wavelengths generated at each node. The second feature is that because each signal is restricted to a particular path, it is possible to have each wavelength reused many times on different paths throughout the network as long as these other paths do not try to coexist on the same fiber link. A schematic of such type of switching node with wavelength converters for wavelength reusing is shown in Figure 2. Such a wavelength interchanging cross-connect allows any input wavelength on any input fiber to be cross-connected with any output wavelength on any output fiber, provided that the desired fiber has enough channels. This switch partially achieved both wavelength and space (among fiber links) multiplexing.

The importance of the DWDM cross-connect switch, and the closely related DWDM add-drop multiplexer, is that they allow the optical network to be reconfigured on a wavelength-by-wavelength basis to optimize traffic, congestion, network growth, and survivability. They also permit the configuration of special circuits for transmission of alternative format signals. The DWDM cross-connect switch and the DWDM add-drop multiplexer are the essential wavelength-selective format transparent elements upon which multi-wavelength networks will be built.

3.0 DWDM Applications in the Near Future

The first application of DWDM is point-to-point backbone transmissions, which is currently being deployed in many cases. It can be applied to different network frameworks and protocols, such as the circuit switched Synchronous Optical NETwork (SONET, known as the Synchronous Digital Hierarchy (SDH) in Europe), the TCP/IP based Internet, TCP/IP or ATM based Intranet, etc. The applications of DWDM point-to-point will dramatically expand the bandwidth capacity of existing fiber links. It will, therefore, potentially reduce the costs of these networks. One network that seems being left out by this step of DWDM application will be the cable TV network. Although it is possible to replace the coaxial cables by optical fibers and run DWDM for broadcast television services with each wavelength carrying one or more TV channels, the costs may again become the defining factor.

The technologies for interconnecting existing communication networks and protocols with DWDM point-to-point backbones are in the developing stage. Some of these technologies are already commercially available. There are no technological obstacles for building the interface between DWDM and most existing networks. Product development is the current status in this area.

The second step of DWDM applications will be adding optical switches/routers onto the DWDM backbone networks. At this stage, the architecture and the protocol of a network will determine the costs and even the possibility of implementing the switches/routers. Considering the mechanisms of the current networks, including the SONET, the Internet, the ATM, and the cable TV system, the SONET will be the leader in this stage, because of the simplicity of its switching and time domain multiplexing (TDM) mechanisms in comparison with the rest. It is foreseeable to replace the electrical digital switches and its time domain multiplexers by its optical counterparts, while it is much more difficult to replace the routers in the Internet and the switches in the ATM networks, since the control of these routers/switches requires higher intelligence to run the protocols. Therefore, it would not be surprising to see a full optical SONET or SDH in the foreseeable future, while we might have to wait somewhat longer to see a full optical packet switching network.

4.0 Optical DWDM Networks & Integrated Services

A further development after the optical circuited SONET would be packet switching/routing full optical integrated services network. If we compare the suitability between ATM and TCP/IP, it is obvious that the ATM becomes the leader, since the TCP/IP has not yet had the capacity for real-time communications. However, research on enabling the Internet to provide quality of service (QoS) is currently on going in the Internet community. With the DWDM backbone being in place in the near future, which will provide much higher bandwidth between routers, the research on the next generation of the real-time Internet will gain momentum. The major bottleneck comes from the capacity of the electronic routers, which might delay or even prevent the implementation and the test of the QoS enabled TCP/IP protocols.

To implement the full optical ATM switches, a major obstacle comes from the control unit of the switch that is responsible for executing the protocols. The switching fabrics are in the same level of SONET switches in terms of optical implementations. The implementation of the control unit requires logic processing in the light domain. Technologies for logical processing in the light domain are not available at the moment, although it is possible in theory.

To implement the full optical QoS enabled TCP/IP, if we assume that it is ready, we need full optical computers. This will require a revolution in the computer design and manufacturing, but it seems possible. TCP/IP over ATM may find its application again in a full optical ATM over DWDM network.

5.0 Concluding Comments

The article provides an overview of DWDM networks and its current technologies. Analyses of applications and roles of current network protocols in the future DWDM frameworks are also provided. It seems clear that DWDM will reshape communication networks, but the current network architectures and protocols will play their roles in the future DWDM based framework. Because of the switching simplicity and bandwidth availability through DWDM, SONET may well be the first framework for a full optical network. Although ATM has been losing its popularity due to the lack of success of the B-ISDN, it may find a new life on ATM over DWDM for future integrated services networks.

6.0 References

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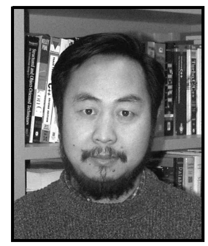
7. Acronyms

ATM	- Asynchronous Transfer Mode
B-ISDN	- Broadband Integrated Services Digital Networks
DWDM	- Dense Wavelength Division Multiplexing
FDM	- Frequency Domain Multiplexing
QoS	- Quality of Service
SDH	- Synchronous Digital Hierarchy
SONET	- Synchronous Optical Network
TDM	- Time Domain Multiplexing
TCP/IP	- TCP: Transmission Control Protocol IP: Internet Protocol
WDM	- Wavelength Division Multiplexing

About the Author



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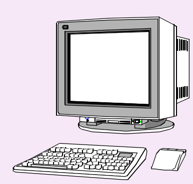
Proverbs for the Millennium

1. Home is where you hang your @.
2. The e-mail of the species is more deadly than the mail.
3. A journey of a thousand sites begins with a single click.
4. You can't teach a new mouse old clicks.
5. Great groups from little icons grow.
6. Speak softly and carry a cellular phone.
7. C:\ is the root of all directories.
8. Oh, what a tangled website we weave when first we practice.
9. Pentium wise, pen and paper foolish.
10. The modem is the message.
11. Too many clicks spoil the browse.
12. The geek shall inherit the earth.
13. There's no place like home.
14. Don't byte off more than you can view.
15. Fax is stranger than fiction.
16. What boots up must come down.
17. Windows will never cease.
18. Virtual reality is its own reward.
19. Modulation in all things.
20. Give a man a fish and you feed him for a day; teach him to use the Net and he won't bother you for weeks.



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