International Journal of Electronics and
Communication Engineering (IJECE)
ISSN(P): 2278-9901; ISSN(E): 2278-991X
Vol. 2, Issue 5, Nov 2013, 29-36

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DWDM TECHNOLOGY FOR OPTIMUM USE OF OPTICAL NETWORK

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ABSTRACT

Initial stages of the Public Switched Telephone Networks (PSTN) used copper cables for propagation of electric signals. With the invention of optical fiber), an efficient, lossless and high capacity waveguide was introduced. However the factors of cost - in terms of laying, maintaining and construction - and fragility put a strain on the use of fibers in commercial applications. The traditional Time Division Multiplexing has proved to restrict the use of fibers from its full capacity. A new technology in the field of multiplexing called Dense Wave Division Multiplexing (DWDM) has created a breakthrough by eliminating the strain on the wave carrying capacity of a fiber and multiplied the bandwidth provided by optical channels. DWDM has also eliminated a number of drawbacks of conventional switching networks. It has hence proved to be the future technology in optical fiber networks.

KEYWORDS: Cross Connectors, DWDM, Grating, OADM, OEO Regeneration, Optical Fibers, PSTN

INTRODUCTION

Optical Bands

Out of the entire wavelength spectrum available, each section has been designated to be used by a particular transmission medium. This designation is according to the properties of the particular medium. Based on this, Optical fibers have been allotted a part of the infrared band of light with wavelength limits of 800 nm to 1600nm. Further segregation of the bands by the ITU has been made as per the Table 1.

Table 1: Optical Bands

Optical Bands	Wavelengths
O (Original)-Band	1260 nm - 1360 nm
E (Extended)-Band	1360 nm - 1460 nm
S (Short)-Band	1460 nm - 1530 nm
C (Conventional)-Band	1530 nm - 1565 nm
L (Long)-Band	1565 nm - 1625 nm
U (Ultralong)-Band	1625 nm - 1675 nm

Current Scenario

Traditionally optical links that have been used in PSTN have used time division multiplexing of channels for transmission. The techniques and protocols used are similar to those used in copper cable transmission. However given the enormous bandwidth and data carrying capacity of optical fibers, these multiplexing techniques have proved to under-utilize the fiber. These are due to the following factors involved in usage of optical fibers:

- **Bandwidth**

Techniques of time division multiplexing such as PDH and SDH provide minimal bandwidth of a maximum of 2.5 GB/s (STM-16). These levels of bit rates are rendered insufficient for current data and voice transmission at high speed. This is due to the increased traffic and more data centric applications over the network.

- **Cost**

The major disadvantage of optical fiber networks is the high cost involved in laying, maintaining and management of fiber cables. This can be attributed to the properties of the fiber such as brittleness, cost of material, etc. Thus optical links have been confined in the use to high traffic and bandwidth extensive networks.

- **Attenuation**

Although optical fibers are known for their almost lossless transmission of light, a noticeable attenuation over a distance of 40 km occurs. Due to this regeneration has to be carried out by optical electrical-optical (OEO) regeneration. Hence there is a need of a low power consuming network which relies on direct optical repeating and amplification.

WAVELENGTH DIVISION MULTIPLEXING

Wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signal wavelengths onto a single optical fiber by using different wavelengths (i.e. colors) of laser light. The different wavelengths of light can also be understood as different colors of light used in the infrared region. It is analogous to Frequency division multiplexing (FDM) used in electrical and radio wave transmission. This technology can be implemented due to the property of light by which well spaced wavelengths of light do not interfere while traveling in the same medium.

WDM has provided a breakthrough in optical network technology by multiplying bandwidth capacity and providing flexibility and reusability to the currently installed networks. The fundamental principle used is shown in Figure 1.

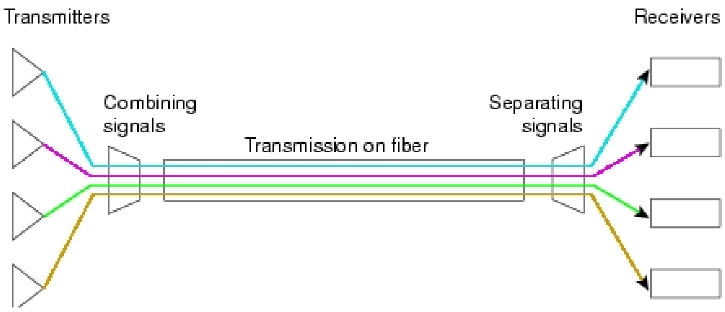

Figure 1: Wavelength Division Multiplexing

As per the figure various channels are converted to light signals of different wavelengths which are then multiplexed (added) into the single fiber for transmission. At the receiving end the different wavelengths are filtered and converted back into electrical form.

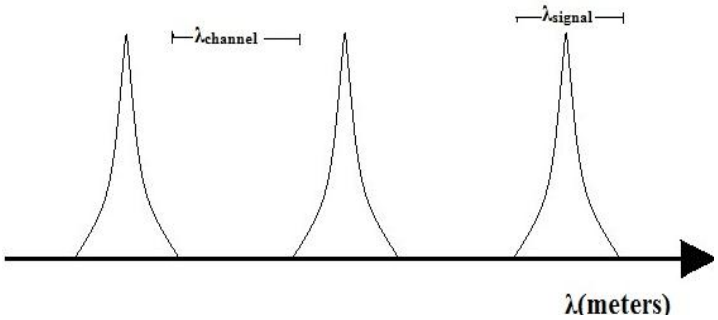

Figure 2: Wavelength Spectrum Division

The wavelength used and the spacing between adjacent wavelengths are important parameters required to measure the efficiency and scalability of such systems.

Based on this WDM is classified into two parts:

- **Coarse Wavelength Division Multiplexing (CWDM)**

This type is characterized by its wide spectrum usage and large wavelength spacing's. As per this method, up to 20 wavelengths can be multiplexed and transmitted. The ITU-T standardization for CWDM (ITU-T G.694.2), specifies wavelength usage from 1271nm to 1610nm with a channel spacing of 20nm. This gives 17 channels over the entire band. But this technique has proved to be futile due to the increased attenuation over the 1271 to 1611nm band, thus further decreasing the number of channels. The main characteristic of the recent ITU CWDM standard is that the signals are not spaced appropriately for amplification by erbium doped fiber amplifiers (EDFAs), by which the optical-electrical-optical conversion is eliminated.

- **Dense Wavelength Division Multiplexing (DWDM)**

This is characterized by its relatively narrow spectrum usage and smaller bandwidth spacing's. As per this method, more than 20 wavelengths can be multiplexed and transmitted. The ITU-T standardization for DWDM (ITU-T G.694.1), specifies reference wavelength fixed at 1552.52nm with channel spacing of 0.8nm. Thus, a number of wavelengths can be added around the reference wavelength. The usage of the C and L bands enables the use of EDFAs. Although CWDM possesses the advantages of simplicity and low electric power usage by using passive optical filters, it has not helped exploit the enormous capacity of optical fibers. Hence a number of PSTN and cable television networks are employing DWDM for faster and high capacity transmission.

MULTIPLEXING / DEMULTIPLEXING TECHNIQUES

The different techniques used for multiplexing / demultiplexing of light for transmission over a link are as follows:

- **Diffraction Grating**

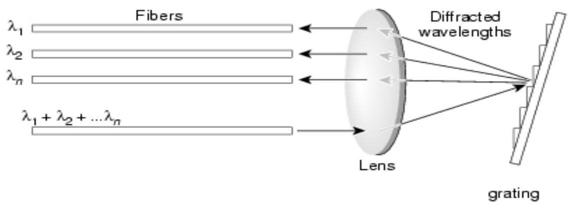

Figure 3: Diffraction Grating Mechanism

It is based on the principles of diffraction and of optical interference. When a polychromatic light source impinges on a diffraction grating, each wavelength is diffracted at a different angle and therefore to a different point in space. Using a lens, these wavelengths can be focused onto individual fibers.

- **Arrayed Waveguide Grating**

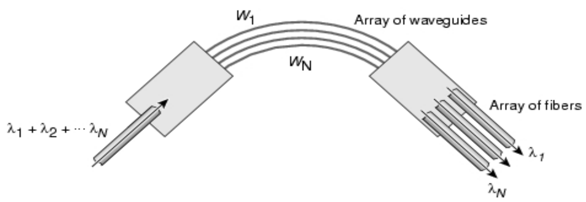

Figure 4: Array Waveguide Grating Mechanism

It is essentially a multistage, multi cross-connect wavelength coupler. The delay line between the two sides cause different phase shifts for different wavelengths and therefore different wavelengths from one input appear at different outputs.

- **Thin Film Filter**

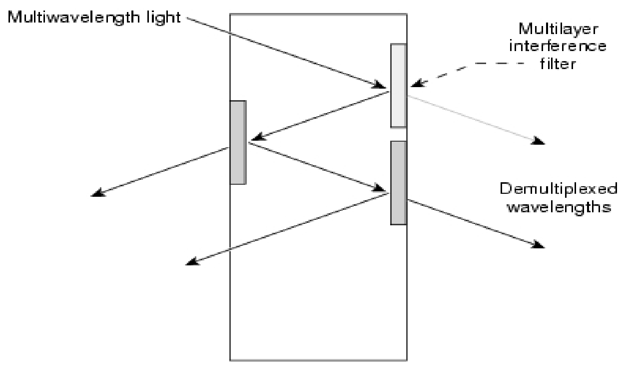

Figure 5: Thin Film Filtering Mechanism

A different technology uses interference filters in devices called thin film filters or multilayer interference filters. By positioning filters, consisting of thin films, in the optical path, wavelengths can be sorted out (demultiplexed). The property of each filter is such that it transmits one wavelength while reflecting others. By cascading these devices, many wavelengths can be demultiplexed.

DWDM ARCHITECTURE

The various components of a basic DWDM system are:

- The wavelength converting *transponders* receive the input optical signal (i.e., from a client-layer SDH, PDH, IP or other signal), converts that signal into a corresponding wavelength depending on the band of wavelength used. The spacing for the adjacent wavelengths generated is 0.8nm in case of DWDM.
- The wavelength *multiplexer* is used to combine these equally spaced wavelength signals, to a single beam of light to be transmitted. The signal obtained from the multiplexer is fed into a booster amplifier for adequate power to be pumped into the system. They also provide an interface for the online monitoring of combined light. The four types of optical multiplexer unit boards are OMU8, OMU16, OMU32 and OMU40.
- The *optical amplification units* are line amplifiers used to boost signal power. The amplifiers used are erbium doped fiber amplifiers (EDFA). These amplifiers use direct optical amplification as compared to traditional optical-electric-optical amplifiers. They provide functions such as gain adjustment, gain lock, and power clamp function. In addition, they also add/drop the supervisory wavelength of 1510nm.
- *Optical add-drop multiplexers* are used to provide flexibility to a network by extracting or inserting wavelengths in the network link. The fixed wavelengths to be added or dropped depending on the customer's requirements. These components use direct optical adding and dropping of wavelengths. Thin-film filters have emerged as the technology of choice for OADMs in current metropolitan DWDM systems because of their low cost and stability. The four types of optical add/drop multiplexer boards are OAD1, OAD2, OAD4 and OAD8.
- The *optical demultiplexer unit* is used to convert the beam of light received into equally spaced wavelengths at the receiving side. The original wavelengths are very accurately reproduced due to negligible dispersion and polarization of the wave. They also provide an interface for online monitoring of multiplexed systems. The four types of optical demultiplexer unit boards are ODU8, ODU16, ODU32 and ODU40.

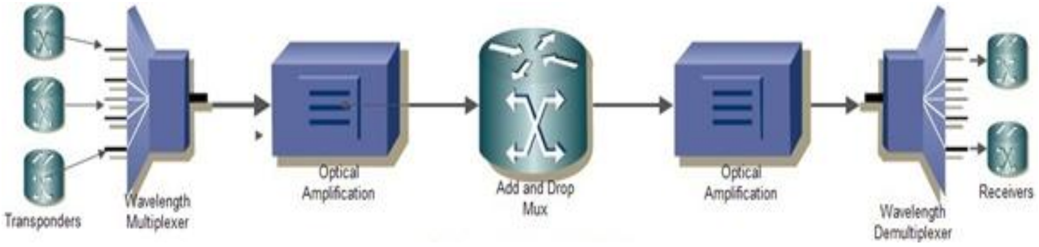

Figure 6: DWDM System Architecture

DWDM TREND

The brief time line in the development of DWDM technology is:

- **Optical Terminal Multiplexer**

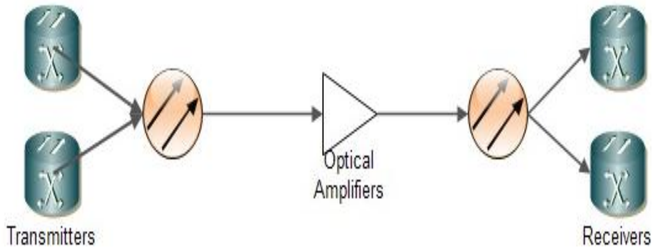

Figure 7: Optical Terminal Multiplexer

This technology was invented in the 1990's. It merely consisted of an optical multiplexer at the end points of a point-to-point network.

- **Optical Add Drop Multiplexer**

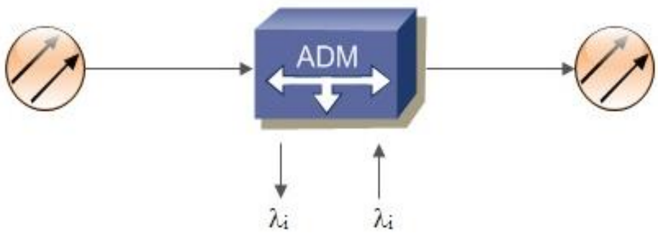

Figure 8: Optical Add Drop Multiplexer

This technology was invented in the year 2006. Networks have become more flexible and manageable due to this component.

- **Optical Cross Connect**

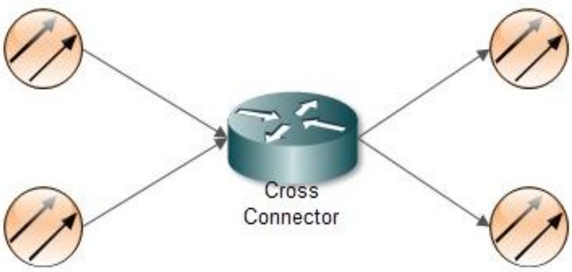

Figure 9: Optical Cross Connect

This is a comparatively new technology. These components are used for high speed optical switching. It can be viewed as a more generalized case of OADM.

ADVANTAGES AND DISADVANTAGES

Advantages

DWDM systems have proved to be an effective way to take optical network technology to the next level by providing a number of advantages. Even though replacing traditional equipment with new ones has been a costly affair, a number of pros have nurtured the implementation of this technology in current public switched telephone network (PSTN) and especially the ever service demanding metropolitan area networks (MAN) due to the following reasons:

- **Multiprotocol Support**

DWDM is a physical layer architecture which supports multiple protocols at the transport, network and the link layer. Various TDM techniques like Synchronous Digital Hierarchy (SDH) and plesiochronous digital hierarchy (PDH), as well as data formats such as Internet Protocol (IP), Gigabit Ethernet, ESCON, Asynchronous Transfer Mode (ATM), etc. in the open or integrated type of systems as specified by ITU-T G.692 standard.

- **Cost Effectiveness**

Existing systems can be enhanced by DWDM systems in rapidly growing networks. Capacity can be obtained for the cost of the equipment, and existing fiber investment is retained. As demands change, more capacity can be added, either by simple equipment upgrades or by increasing the number of lambdas on the fiber, without expensive upgrades.

- **Scalability**

DWDM can leverage the abundance of dark fiber in many metropolitan area and enterprise networks to quickly meet demand for capacity on point-to-point links and on spans of existing SONET/SDH rings.

- **Ease of Management**

DWDM based networks are easy to manage due to the presence of the Optical Supervision Control (OSC) and the Add Drop Multiplexer (ADM). The supervision control helps in monitoring line amplifier gain and other transmission parameters. The ADM helps manage specific channels in the network.

- **Power Consumption**

The power consumption in DWDM systems is minimal due to the minimum attenuation to the signal. The use of an EDFA is required only after a distance of 120 km. during which the wave attenuation is roughly 10db. The direct optical amplification of the amplifier further reduces the power consumption.

Disadvantages

A few inherent drawbacks of DWDM systems are:

- These systems are not effective for low channel numbers due to the fixed cost of the multiplexers, demultiplexers, transponders and other system components.
- Current network management systems in SDH are not well equipped to handle DWDM topologies.

APPLICATIONS

DWDM architecture has found its way into a number of commercial networks such as:

- High-traffic long haul routes.

- Enterprise Networks.
- Metropolitan Area Networks (MAN).
- Inter-continental (submarine) routes.
- Extension of network to congested areas.

CONCLUSIONS

Within the DWDM industry the combination of four key technologies- advanced modulation (QPSK/QAM), polarization multiplexing, coherent detection and high speed DAC/ADC with advanced signal processing – represents the state of the art in efficient DWDM transmission. These coherent technologies have transformed 10G to 100G per DWDM channel and improved line rate and spectral efficiency.

In the current data hungry network, where traditional voice data is being replaced by Voice over IP (VoIP), DWDM systems have proved to make networks more reliable and scalable. DWDM architecture is also going to be the physical layer basis of many data centric future protocols of the network and link layer. Thus industries leading coherent transmission performance and multi-carrier super-channels have been realized due to DWDM technology.

ACKNOWLEDGEMENTS

I would like to thank the faculty of the Electronics department of D. J. Sanghvi College of Engineering from guiding me and giving their feedback on the data of this paper. I would also like to thank them for the resources provided in order to facilitate the study and research over this topic. I would also like to thank Edraw Max for providing an efficient way of creating network architecture figures.

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