Dense Wavelength Division Multiplexing (DWDM) : A Review

Prabir Kumar Sethy
Lecturer, Dept. of ECE, SUIIT
Sambalpur ,Odisha 768019, India

Kamal Pradhan
Dept. of CSE, SUIIT
Sambalpur ,Odisha 768019, India

Dr. Madhumita Panda
Lecturer, Dept. of CSE, SUIIT
Sambalpur ,Odisha 768019, India

Abstract—it is clear that as we approach the 21st century the remarkable revolution in information services has permeated our society. This rapid growth of information technology has led to new services hungry for transmission capacity. Communication, which in the past was confined to narrowband voice signals, now demands a high quality visual, audio, and data context for services such as Voice over-Internet protocol (VoIP), video streaming, broadcasting of TV programmes, high-speed file sharing, E-commerce and E-Governance need a transmission medium with very high bandwidth capabilities for handling vast amounts of information. The telecommunications industry, however, is struggling to keep pace with these changes. Earlier predictions were made that current fiber capacities would be adequate for our needs into the next century but they have been proven wrong but these fiber-optics, with its comparatively infinite bandwidth and by employing the latest multiplexing technique, i.e. Dense Wavelength Division Multiplexing (DWDM) has proven to be the solution.

Keywords— SONET, EDFA; Optical window; SDH, FWM

1. INTRODUCTION

There are certain key characteristics of acceptable and optimal DWDM systems. These characteristics should be in place for any DWDM system in order for carriers to realize the full potential of this technology [6].

DWDM technology utilizes a composite optical signal carrying multiple information streams, each transmitted on a distinct optical wavelength [5]. Although wavelength division multiplexing has been a known technology for several years, its early application was restricted to providing two widely separated "wideband" wavelengths, or to manufacturing components that separated up to four channels. Only recently has the technology evolved to the point that parallel wavelengths can be densely packed and integrated into a transmission system, with multiple, simultaneous, extremely high frequency signals in the 192 to 200 terahertz (THz) range. By conforming to the ITU channel plan, such a system ensures interoperability with other equipment and allows service providers to be well positioned to deploy optical solutions throughout their networks. The 16 channel system in essence provides a virtual 16–fiber cable, with each frequency channel serving as a unique STM–16/OC–48 carrier.

Exploiting the transmission carrying capability of optic fiber, another standard, known as synchronous optical network (SONET), with designations ranging from OC-1 to OC-192 has been developed (Table I) [3]. These optical signals can be transmitted over distances up to 100km without the need of repeaters [1] [4].

A synchronous digital hierarchy (SDH) system has been developed in which each rate is an exact multiple of the lower rate [2]. SDH is a transport hierarchy based on multiples of 155.52Mbps. The basic unit of SDH is synchronous transmission module level-1 (STM-1) (Table I) [3].

Transmission rates of up to 40Gbps can be achieved in modern SDH systems. Even though OC-192 is the maximum data rate specified by SONET, recent developments in SDH technology allow for transmission as high as 40Gbps [1] [2].

The existing SONET/SDH network architecture is best suited for voice traffic rather than today's high-speed data traffic [4]. To upgrade the system to handle this kind of traffic is very expensive and hence the need for the development of an intelligent all-optical network is aroused. The solution is to use frequency multiplexing at the optical level or wavelength division multiplexing (WDM/DWDM). Here, the basic idea is to use different optical carriers or colors to transmit different signals in the same fiber.

Such a network will bring intelligence and scalability to the optical domain by combining the intelligence and functional capability of SONET/SDH, the tremendous bandwidth of DWDM and innovative networking software to spawn a variety of optical transport, switching and management related products. This coupled with the availability of 32-channel and 96-channel WDM has led to the development of systems capable of 320Gbps to 1.2 terabit-per-second transmission.

2. Evolution of DWDM

Early WDM began in the late 1980s using the two widely spaced wavelengths in the 1310nm and 1550nm (or 850nm and 1310nm) regions, sometimes called wideband WDM. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were spaced at an interval of about 400GHz in the 1550nm window. Traditional passive WDM systems were widespread with 2-, 4-, 8-, 12- and 16-channel counts. This technique usually has a distance limitation of less than 100km, without any repeater stage.

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 8 (September 2014) www.ijirae.com

Another variant of WDM, known as coarse WDM (CWDM), typically used 20nm spacing of up to 18 channels that could reach a target distance up to about 50km on single-mode fibers. By the mid-1990s, dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100GHz to 200GHz. By the late 1990s, DWDM systems were capable of 64 to 160 parallel channels, densely packed at 50GHz or even 25GHz intervals at distances of several thousand kilometers with amplification and regeneration along the route. Interestingly, in a WDM network, the vast optical bandwidth of a fiber (approximately 30THz) is carved up into wavelength channels, each of which carries a data stream individually. The multiple channels of information (each having a different carrier wavelength) are transmitted simultaneously over a single fiber (Fig. 1).

Table I

Telecom Transmission Designations

Standard/ Medium	*Designation*	*Data Rate (Mbps)*	*Number Of Voice Channels*
The north American Digital Telephony System/Copper	DS-1	1.544	24
	DS-2	6.312	96
	DS-3	44.736	672
	DS-4	274.176	4032
SONET (synchronous optical network)/ optical fiber	OC-1	51.84	672
	OC-3	155.52	2016
	OC-12	622.08	8064
	OC-18	933.12	12,096
	OC-24	1244.16	16,128
	OC-36	1866.24	24,192
	OC-48	2488.32	32,256
	OC-96	4976.64	64,512
	OC-192	9953.28	129,024
Synchronous digital hierarchy (SDH)/ optical fiber	STM-1	155.52	2016
	STM-4	622.08	8064
	STM-16	2488.32	32,256
	STM-64	9953.28	129,024

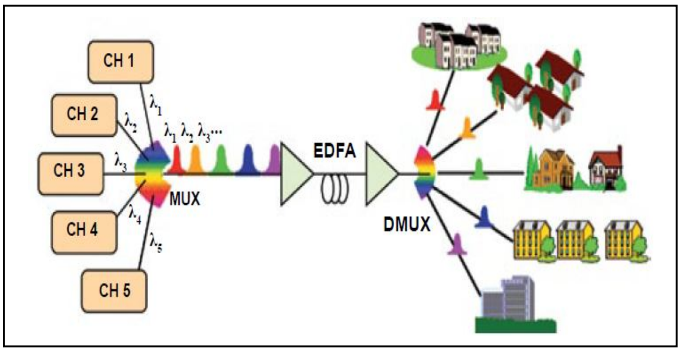

Fig. 1. Block diagram of DWDM system.

Table II

Optical Transmission Window

Optical Window	*Operating Wavelength*
800-900nm	850nm
1250-1350nm	1310nm
1500-1600nm	1550nm

The reason why this can be done is that optical beams with different wavelengths propagate without interfering with one another. When the number of wavelength channels is above 20 in a WDM system, it is generally referred to as dense WDM or DWDM. Optical fiber transmission uses wavelengths that are in the near-infrared portion of the spectrum, just above the visible and thus undetectable to the unaided eye. There are ranges of wavelengths known as transmission windows at which the fiber operates best (Table II).

These wavelengths best match the transmission properties of available light sources with the transmission qualities of optical fiber. Usually, LEDs are used for 850nm or 1310nm multimode applications and lasers are used for 1310nm or 1550nm single-mode applications. For DWDM system, 1550nm window has been chosen due to low attenuation characteristics of glass at 1550nm and the fact that erbium doped fiber amplifiers (EDFAs) operate in the 1530nm-1570nm range. The International Telecommunications Union (ITU) defines a frequency grid that specifies standard frequency spacing as 100GHz, which translates into 0.8nm wavelength spacing.

3. DWDM system components

- ***Transmitter and receiver***

A transmit transponder is used at transmitter's side to change electrical signals into ITU grid-specific optical wavelengths. For this purpose, it employs a narrow band of laser to generate optical pulses. At the receiver's side, a receive transponder converts optical pulses to electrical signal, if required. In these systems, small form-factor pluggable (SFP) transceivers are used to interface the system with the fiber-optic cable.

- ***Transmission media***

Due to minimum fiber-optical attenuation at 1550nm and availability of optical amplifiers in 1550nm region, most of the DWDM systems operate in C-band, that is, from 1530nm to 1565nm. In this range, conventional single-mode optical fibers (ITU G.652 compliant) undergo high dispersion, which severely limits the distance between repeater stations. Solutions lie in the use of dispersion compensating fiber (DCF) and zero dispersion fiber (ITU G.653 compliant). But, DCF adds additional power loss and zero dispersion fiber results in nonlinearity such as four-wave mixing (FWM). A fiber that has small but non-zero amount of dispersion can minimize the non-linearity effects. The ITU G.655 compliant, non-zero dispersion fiber (NZDF) has dispersion which is carefully chosen to be small enough to enable high-speed transmission over long distances, but large enough to suppress FWM. So, ITU G.652 is preferred for access network and ITU G.655 for backbone network. In summary, a future-proof fiber-optic DWDM network should have a combination of ITU G.652 and G.655 fibers.

- ***WDM MUX and DMUX***

Wavelength division multiplexer/de-multiplexer combines/separates discrete signals transmitted at different wavelengths. Essentially, the multiplexer is a mixer and the de-multiplexer is a wavelength filter. Wavelength-division de-multiplexers use several methods (bulk optical diffraction gratings or interference filters for spacing between 1nm and 2nm or fiber Bragg gratings (FBGs) for spacing less than 0.8nm) to separate different wavelengths depending on the spacing between the wavelengths. FBGs are of critical importance in DWDM systems in which multiple closely-spaced wavelengths require separation. Light entering the FBG is diffracted by the induced period variations in the index of refraction. By spacing the periodic variations at multiples of the half wavelength of the desired signal, each variation reflects light with a 360-degree phase shift, causing a constructive interference of a very specific wavelength while allowing others to pass.

- ***Optical amplifier***

In DWDM system, a pre-amplifier is used to boost the signal pulses at the receiver’s side and a post-amplifier boosts signal at the transmitter’s side. In-line amplifiers are placed at different points (usually every 50-60km) from the source to provide recovery of the signal before it is degraded significantly. EDFA is the most popular optical amplifier used to boost the signal level in the 1530nm to 1570nm region of the spectrum. Most importantly, EDFAs allow signals to be regenerated without having to be converted back to electrical signals. In this amplifier, an external laser source of either 980nm or 1480nm is used to pump it and considerably high amplification of the order of 30dB is achieved.

- ***Regenerator***

If the length to be bridged is too long to be covered, regenerators are employed. These regenerators perform real 3R functions—reshaping, retiming and amplification of the signal. Therefore the signals have to be de-multiplexed, electrically regenerated and multiplexed again.

- ***Optical add/drop multiplexer***

In a DWDM system, optical add/drop multiplexer is used to add or drop some specific wavelengths from the already multiplexed optical signal. Such add/drop multiplexer may use complete de-multiplexing or other techniques. A fiber-optic circulator employing FBG may be used to drop any specific wavelength and pass the others.

4. DWDM system

DWDM is an optical multiplexing technology that allows many discrete transport channels, by combining and transmitting multiple signals simultaneously at different wavelengths, on the same fiber. In effect, one fiber is transformed into multiple virtual fibers. So, if you were to multiplex 32 STM-16 signals into one fiber, you would increase the carrying capacity of that fiber from 2.5Gbps to 80Gbps. because of DWDM, single fibers have been able to transmit data at speeds up to 400Gbps. A key advantage to DWDM is that it is protocol and bit-rate independent. DWDM-based networks can carry different types of traffic at different speeds over an optical channel, and so can transmit data in SDH, IP, ATM and Ethernet. Such a DWDM system is shown in Fig. 2 where DWDM and EDFA are used to transmit several channels of high bandwidth information over a single fiber.

These signals are converted into corresponding wavelengths of light in accordance with the ITU grid and are multiplexed with the help of multichannel coupler or wavelength division multiplexer. In order to minimize back reflections, an optical isolator is used with each optical source. Multiplexed optical signal is then routed through a single optical fiber cable. After covering a distance of 50-100km, the signal needs to be amplified. So, several stages of amplification using EDFA are required in order to cover long distances. In order to add or drop some channels, an optical circulator in conjunction with FBG is used. After amplification, a wideband wavelength division multiplexer is used to combine 1310nm signal with the 1550nm window signals. At the receiver’s side, 1310nm signal is extracted via another wideband wavelength division de-multiplexer. Finally, a dense wavelength division de-multiplexer that is made of an array of FBGs, each tuned to specific transmission wavelength, separates all the 1550nm window signals. A tap coupler is used to couple some amount of optical power for wavelength and power measurement.

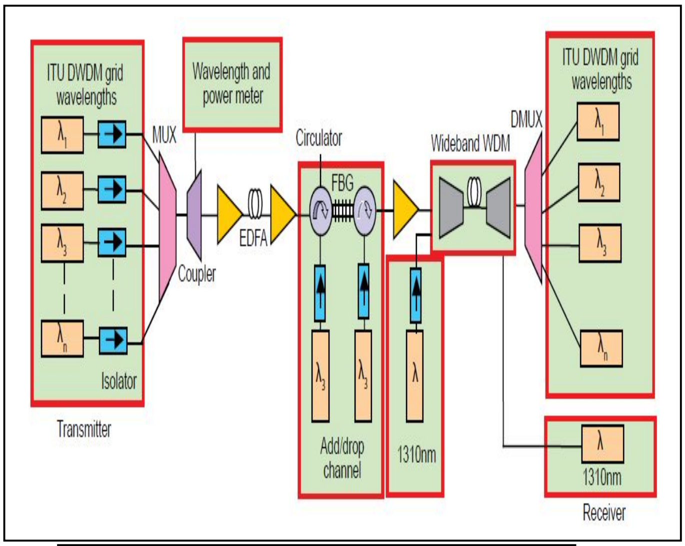

Fig.2. A Typical DWDM system

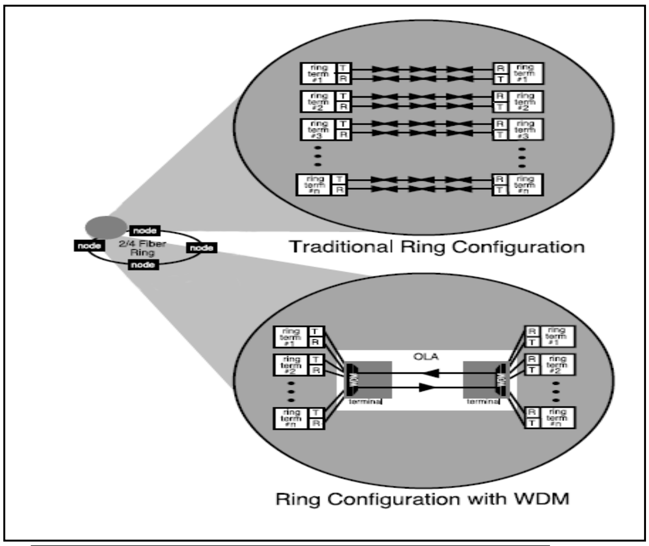

Fig.3. Ring configuration of SONET

5. Applications of DWDM

As occurs with many new technologies, the potential ways in which DWDM can be used are only beginning to be explored. Already, however, the technology has proven to be particularly well suited for several vital applications.

• DWDM is ready made for long-distance telecommunications operators that use either point–to–point or ring topologies. The sudden availability of 16 new transmission channels where there used to be one dramatically improves an operator's ability to expand capacity and simultaneously set aside backup bandwidth without installing new fiber.

• This large amount of capacity is critical to the development of self-healing rings, which characterize today's most sophisticated telecom networks. By deploying DWDM terminals, an operator can construct a 100% protected, 40 Gb/s ring, with 16 separate communication signals using only two fibers.

• Operators that are building or expanding their networks will also find DWDM to be an economical way to incrementally increase capacity, rapidly provision new equipment for needed expansion, and future–proof their infrastructure against unforeseen bandwidth demands.

• The transparency of DWDM systems to various bit rates and protocols will also allow carriers to tailor and segregate services to various customers along the same transmission routes. DWDM allows a carrier to provide STM–4/OC–12 service to one customer and STM–16/OC–48 service to another all on a shared ring (Fig. 3) [5].

• Network wholesalers can take advantage of DWDM to lease capacity, rather than entire fibers, either to existing operators or to new market entrants. DWDM will be especially attractive to companies that have low fiber count cables that were installed primarily for internal operations but that could now be used to generate telecommunications revenue.

• In regions with a fast growing industrial base DWDM is also one way to utilize the existing thin fiber plant to quickly meet burgeoning demand.

6. Conclusion

Optical networking provides the backbone to support existing and emerging technologies with almost limitless amount of bandwidth capacity. The growth of the fiber-optics industry, including the advances in optical sources and detectors that operate in the 1550nm range, the developments of EDFAs, FBG and mutli-channel DWDM systems, has been explosive over the past five years. Presently, DWDM is one of the hottest emerging market segments in global telecommunications which will enable service providers to maximize their embedded infrastructure and position themselves for the capacity demand of the next millennium.

References

[1] Green, Paul. "Progress in optical networking." *Communications Magazine, IEEE* 39.1 (2001): 54-61.

[2] Wei, G. U. O. "Optimization of Synchronous Digital Hierachy Transmission Network of Power Network." *Distribution & Utilization* 27.4 (2010).

[3] Nick Massa" Fiber Optic Telecommunication.",Springfield Technical Community College ,Springfield, Massachusetts

[4] Dr Rajiv Kumar Singh "High-Speed DWDM Technology.",Electronics for you. May -2014(33-37).

[5] CIENA Corporation, "Dense Wavelength Division Multiplexing" ATG's Communications & Networking Technology Guide Series.

[6] Lucent Technologies, Dense Wavelength Division Multiplexing (DWDM) Tutorial (International Engineering Consortium home page: http://webproforum.com/lucenT3/index.html, last accessed date: February 27, 1999) 1998.

