

An Overview of DWDM Technology & Network

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Abstract— This article covers functions and applications of DWDM system components. The operation of each component is discussed individually. DWDM terminology like Attenuation, dispersion, and optical signal to noise ratio (OSNR) are measures of optical signal quality and are the key factors involved in DWDM system design and operation. From transmitter to receiver, the quality of the optical signal and the path across which it travels determines if it is successfully detected and recovered at the receiving end. A description of each type of signal measure and its relationship to a DWDM system is given.

Index Terms— Dense wavelength division multiplexing (DWDM), Optical transmitters/receivers, DWDM mux/demux filters, Optical add/drop multiplexers (OADMs), Optical amplifiers, Transponders (wavelength converters), Attenuation, dispersion, and optical signal to noise ratio.

1 INTRODUCTION

Dense wavelength division multiplexing (DWDM) is an extension of optical networking. DWDM devices combine the output from several optical transmitters for transmission across a single optical fiber. At the receiving end, another DWDM device separates the combined optical signals and passes each channel to an optical receiver. Only one optical fiber is used between DWDM devices (per transmission direction).

Instead of requiring one optical fiber per transmitter and receiver pair, DWDM allows several optical channels to occupy a single fiber optic cable. A key advantage to DWDM is that it's protocol and bit-rate independent. DWDM-based networks can transmit data in IP, ATM, SONET, SDH and Ethernet. Therefore, DWDM-based networks can carry different types of traffic at different speeds over an optical channel. Voice transmission, e-mail, video and multimedia data are just some examples of services which can be simultaneously transmitted in DWDM systems. DWDM systems have channels at wavelengths spaced with 0.4 nm spacing. DWDM is a type of frequency division multiplexing (FDM). A fundamental property of light states that individual light waves of different wavelengths may co-exist independently within a medium. Lasers are capable of creating pulses of light with a very precise wavelength. Each individual wavelength of light can represent a different channel of information. By combining light pulses of different wavelengths, many channels can be transmitted across a single fiber simultaneously. Fiber optic systems use light signals within the infrared band (1mm to 400 nm wavelength) of the electromagnetic spectrum. Frequencies of light in the optical range of the electromagnetic spectrum are usually identified by their wavelength, although frequency (distance between lambdas) provides a more specific identification.

2. DWDM SYSTEM COMPONENTS

- Optical transmitters/receivers
- DWDM mux/demux filters
- Optical add/drop multiplexers (OADMs)
- Optical amplifiers
- Transponders (wavelength converters)

2.1 Optical Transmitters/Receivers

Transmitters are described as DWDM components since they provide the source signals which are then multiplexed. The characteristics of optical transmitters used in DWDM systems is highly important to system design. Multiple optical transmitters are used as the light sources in a DWDM system. Incoming electrical data bits (0 or 1) trigger the modulation of a light stream.

Example: a flash of light = 1, the absence of light = 0

Lasers create pulses of light. Each light pulse has an exact wavelength (λ) expressed in nanometers (nm). In an optical-carrier-based system, a stream of digital information is sent to a physical layer device, whose output is a light source (an LED or a laser) that interfaces a fiber optic cable. This device converts the incoming digital signal from electrical (electrons) to optical (photons) form (electrical to optical conversion, E-O). Electrical ones and zeroes trigger a light source that flashes (for example; light = 1, little or no light = 0) light into the core of an optical fiber. E-O conversion is non-traffic affecting. The format of the underlying digital signal is unchanged. Pulses of light propagate across the optical fiber by way of total internal reflection. At the receiving end, another optical sensor (photodiode) detects light pulses and converts the incoming optical signal back to electrical form. A pair of fibers usually connects any two devices (one transmit fiber, one receive fiber).

2.1.1 Channel Spacing

DWDM systems require very precise wavelengths of light to operate without interchannel distortion or crosstalk. Several individual lasers are typically used to create the individual channels of a DWDM system. Each laser operates at a slightly different wavelength. Modern systems operate with 200, 100, and 50-GHz spacing. Newer systems support 25 GHz spacing and 12.5 GHz spacing is being investigated.

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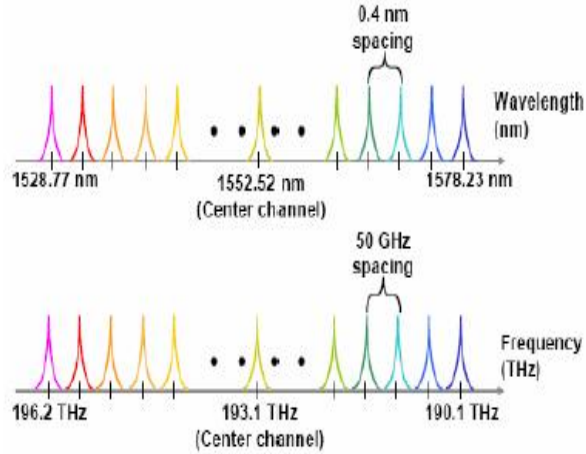


Figure 1

2.2 Dwdm Mux/Demux Filters

Multiple wavelengths (all within the 1550 nm band) created by multiple transmitters and operating on different fibers are combined onto one fiber by way of an optical filter (multiplexer filter). The output signal of an optical multiplexer is referred to as a composite signal. At the receiving end, an optical drop filter (demultiplexer) separates all of the individual wavelengths of the composite signal out to individual fibers. The individual fibers pass the demultiplexed wavelengths to as many optical receivers. Typically, mux and demux (transmit and receive) components are contained in a single enclosure. Optical mux/demux devices can be passive. Component signals are multiplexed and demultiplexed optically, not electronically, therefore no external power source is required.

The block diagram shows in figure 2 is bidirectional DWDM operation. N light pulses of N different wavelengths carried by N different fibers are combined by a DWDM mux. The N signals are multiplexed onto a pair of optical fiber. A DWDM demultiplexer receives the composite signal and separates each of the N component signals and passes each to a fiber. The transmitted and receive signal arrows represent client-side equipment. This requires the use of a pair of optical fibers; one for transmit, one for receive.

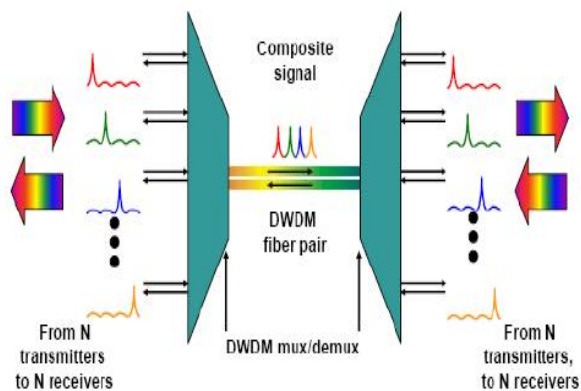


Fig 2. Mux/demux (transmit/receive) components

2.3 Optical Add/Drop Multiplexers

This block diagram demonstrates the operation of a one-channel OADM. This OADM is designed to only add or drop optical signals with a particular wavelength (represented by the red light pulse above). From left to right, an incoming composite signal is broken into two components, drop and pass-through. The OADM drops only the red optical signal stream. The dropped signal stream is passed to the receiver of a client device. The remaining optical signals that pass through the OADM are multiplexed with a new add signal stream. The OADM adds a new red optical signal stream, which operates at the same wavelength as the dropped signal. The new optical signal stream is combined with the pass-through signals to form a new composite signal.

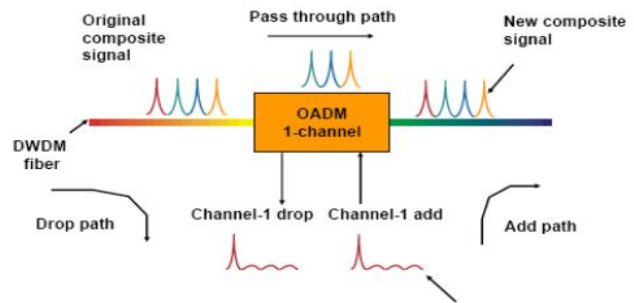


FIG. 3

2.4 Optical Amplifiers

Optical amplifiers (OAs) boost the amplitude or add gain to optical signals passing on a fiber by directly stimulating the photons of the signal with extra energy. They are "in-fiber" devices. OAs amplify optical signals across a broad range of wavelengths. This is very important for DWDM system application. Erbium-doped fiber amplifiers (EDFAs) are the most commonly used type of in-fiber optical fibre.

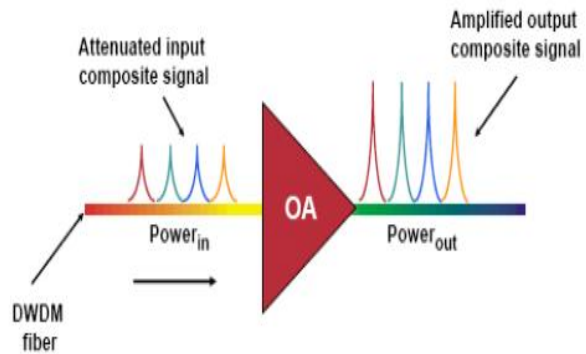


Figure:4

2.5 Transponders (Wavelengths Convertors)

Transponders convert optical signals from one incoming wavelength to another outgoing wavelength suitable for DWDM applications. Transponders are optical-electrical-optical (O-E-O) wavelength converters. A transponder performs an O-E-O operation to convert wavelengths of light. Within the DWDM system a transponder converts the client optical signal back to an electrical signal (O-E) and then performs either 2R (reamplify, reshape) or 3R (reamplify, reshape, and retime) functions. The block diagram shows bi-directional transponder operation. A transponder is located between a client device and a DWDM system. From left to right, the transponder receives an optical bit stream operating at one particular wavelength (1310 nm). The transponder converts the operating wavelength of the incoming bitstream to an ITU-compliant wavelength. It transmits its output into a DWDM system. On the receive side (right to left), the process is reversed. The transponder receives an ITU-compliant bit stream and converts the signals back to the wavelength used by the client device.

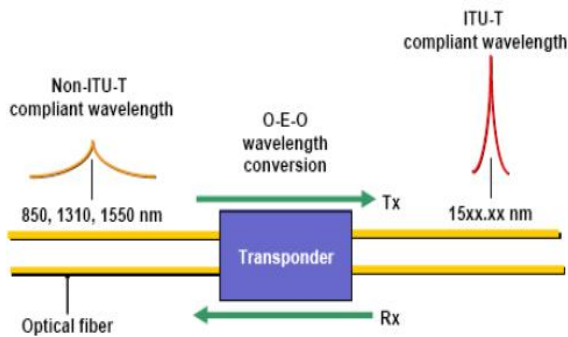


Figure:5

3. DWDM SYSTEM

The following steps describe the block diagram shown below:

- The transponder accepts input in the form of a standard single-mode or multimode laser pulse. The input can come from different physical media and different protocols and traffic types.
- The wavelength of the transponder input signal is mapped to a DWDM wavelength.
- DWDM wavelengths from the transponder are multiplexed with signals from the direct interface to form a composite optical signal which is launched into the fiber.
- A post-amplifier boosts the strength of the optical signal as it leaves the multiplexer.
- An OADM is used at a remote location to drop and add bit streams of a specific wavelength.
- Additional optical amplifiers can be used along the fiber span (line amplifier) as needed.
- A pre-amplifier boosts the signal before it enters the demultiplexer.
- The incoming signal is demultiplexed into individual DWDM wavelengths.

- The individual DWDM lambdas are either mapped to the required output type through the transponder or they are passed directly to client-side equipment.

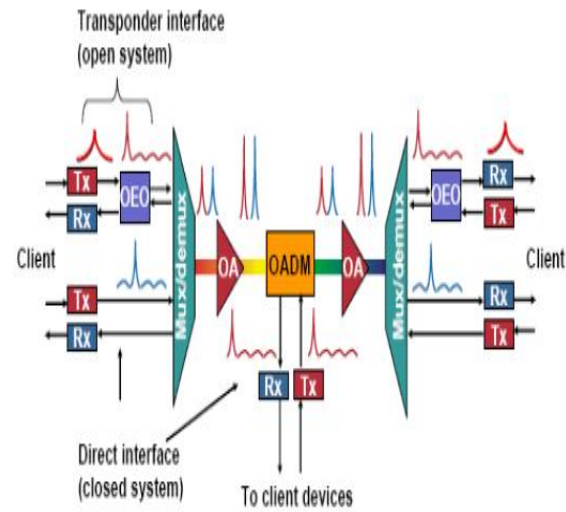


Figure6

4. ATTENUATION

Attenuation is the loss of signal level reported in decibels (dB). Attenuation occurs when impurities in the core and cladding absorb energy from the optical signal. Attenuation is also caused by light "leaking" from the cladding.

4.1 Fiber Loss

Impurities in optical fiber absorb energy from a passing light signal, and is measured in decibels (dB) of loss per length (kilometer) of optical fiber (dB/km). Typical losses are 0.3 dB/km (1550 nm) and 0.5 dB/km (1310 nm).

4.2 Splicing & Connectors Loss

Optical imperfections (air gaps, etc.) found in fiber splices and connectors absorb or deflect energy from a passing light signal. Splice and connector loss is measured in decibels (dB) per splice or connector. Typical values are 0.05 dB/splice and 0.25 dB/connector.

4.3 Insertion Loss

Loss encountered when multiple optical signals are multiplexed together or when a multiplexed signal is demultiplexed. Also, loss related to inserting a device into the optical path, e.g. relating to passing an OADM for a non-affected wavelength. Insertion loss is measured across an optical device (mux/demux, OADM, etc).

5. DISPERSION

Dispersion is the spreading out of a signal as it travels down the fiber. Dispersion results in distortion of the signal which limits the bandwidth of the fiber. Two general types of dispersion affect DWDM systems. One of these effects, chromatic dispersion, is linear while the other, polarization mode dispersion (PMD), is nonlinear. Chromatic dispersion occurs because different wavelengths propagate at different speeds. The effect of chromatic dispersion increases as the square of the bit rate. Polarization mode dispersion (PMD) is caused by ovality of the fiber shape as a result of the manufacturing process or from external stressors. Because stress can vary over time, PMD, unlike chromatic dispersion, is subject to change over time. PMD is generally not a problem at speeds below OC-192.

6. OPTICAL SIGNAL TO NOISE RATIO (OSNR)

OSNR is a measure of the ratio of signal level to the level of system noise. As OSNR decreases, bit detection and recovery errors increase. OSNR is measured in decibels (dB).

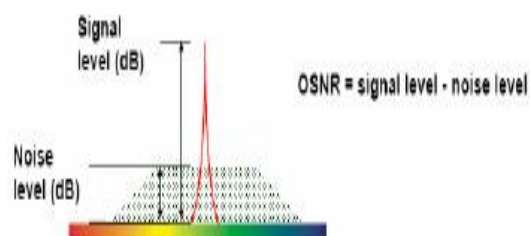


Figure:7

Signal strength reduces over distance in an optical fiber and may need boosting periodically with optical amplifiers, yet the optical gain associated with these amplifiers must be balanced against the additional noise each amplifier introduces. Noise is created by transmitter lasers and optical amplifiers in particular – without optical amplifiers, OSNR will hardly ever affect the bit error rate' (BER) level. Optical amplifiers amplify the optical signals as well as the undesirable noise. The weaker the signal level or the greater the noise level leads to a lower OSNR. Receivers require acceptable levels of OSNR to distinguish signals from system noise.

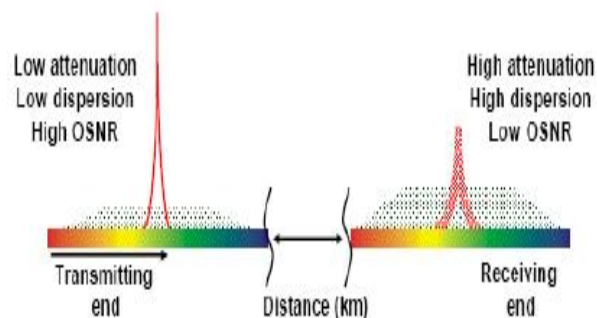


Figure 8

7. CONCLUSIONS

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. The interaction of all the components associated with a DWDM system is critical to system design. From transmitter to receiver, the strength (power level) and quality (OSNR, dispersion) of every optical signal must be maintained. Optical amplifiers extend the reach of DWDM systems by overcoming losses due to attenuation, but could cause OSNR problems. Dispersion compensation devices and dispersion compensated fiber can reduce the amount of dispersion of a particular span, hence increasing the transmission distance.

8. ACRONYMS

DWDM	- Dense Wavelength Division Multiplexing
WDM	- Wavelength Division Multiplexing
OSNR	- Optical signal to noise ratio
O-E-O	- optical-electrical-optical
OA	- Optical amplifiers
EDFA	- Erbium-doped fiber amplifiers
PMD	- Polarization mode dispersion

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