# WDM

**wavelength-division multiplexing** (**WDM**) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e. colors) of laser light. This technique enables bidirectional communications over one strand of fiber, as well as multiplication of capacity.

The term *wavelength-division multiplexing* is commonly applied to an optical carrier (which is typically described by its wavelength), whereas frequency-division multiplexing typically applies to a radio carrier (which is more often described by frequency). Since *wavelength* and *frequency* are tied together through a simple directly inverse relationship, in which the product of frequency and wavelength equals 'c' (the propagation speed of light), the two terms actually describe the same concept.

## Nortel's WDM System

A WDM system uses a multiplexer at the transmitter to join the signals together, and a demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer. The optical filtering devices used have conventionally been etalons (stable solid-state single-frequency Fabry–Pérot interferometers in the form of thin-film-coated optical glass).

The concept was first published in 1978, and by 1980 WDM systems were being realized in the laboratory. The first WDM systems combined only two signals. Modern systems can handle up to 160 signals and can thus expand a basic 10 Gbit/s system over a single fiber pair to over 1.6 Tbit/s.

This is often done by use of optical-to-electrical-to-optical (O/E/O) translation at the very edge of the transport network, thus permitting interoperation with existing equipment with optical interfaces.

WDM systems are divided into different wavelength patterns, **conventional**/**coarse** (CWDM) and **dense** (DWDM). Conventional WDM systems provide up to 8 channels in the 3rd transmission window (C-Band) of silica fibers around 1550 nm. Dense wavelength division multiplexing (DWDM) uses the same transmission window but with denser channel spacing. Channel plans vary, Coarse wavelength division multiplexing (CWDM) in contrast to conventional WDM and DWDM uses increased channel spacing to allow less sophisticated and thus cheaper transceiver designs.

# Coarse WDM

Originally, the term "coarse wavelength division multiplexing" was fairly generic, and meant a number of different things.). Recent ITU standardization of the term, one common meaning for

coarse WDM meant two (or possibly more) signals multiplexed onto a single fiber, where one signal was in the 1550 nm band, and the other in the 1310 nm band.

CWDM is also being used in cable television networks, where different wavelengths are used for the *downstream* and *upstream* signals. In these systems, the wavelengths used are often widely separated, for example the downstream signal might be at 1310 nm while the upstream signal is at 1550 nm.

Passive CWDM is an implementation of CWDM that uses no electrical power. It separates the wavelengths using passive optical components such as bandpass filters and prisms. Many manufacturers are promoting passive CWDM to deploy fiber to the home.

# Dense WDM

Dense wavelength division multiplexing (DWDM) refers originally to optical signals multiplexed within the 1550 nm band so as to leverage the capabilities (and cost) of erbium doped fiber amplifiers (EDFAs), which are effective for wavelengths between approximately **1525–1565 nm (C band),** or **1570–1610 nm (L band)**. EDFAs can amplify any optical signal in their operating range, regardless of the modulated bit rate. In terms of multi-wavelength signals, so long as the EDFA has enough pump energy available to it, it can amplify as many optical signals as can be multiplexed into its amplification band. EDFAs therefore allow a single-channel optical link to be upgraded in bit rate by replacing only equipment at the ends of the link, while retaining the existing EDFA or series of EDFAs through a long haul route.

## DWDM systems

At this stage, a basic DWDM system contains several main components:

1. A DWDM **terminal multiplexer**. The terminal multiplexer contains a 'wavelength converting transponder' for each data signal, an optical multiplexer and where necessary an optical amplifier (EDFA). Each 'wavelength converting transponder' receives an optical data signal from the client-layer, such as Synchronous optical networking [SONET /SDH] or another type of data signal, converts this signal into the electrical domain and re-transmits the signal at a specific wavelength using a 1550 nm band laser. These data signals are then combined together into a 'multi-wavelength optical signal' using an optical multiplexer, for transmission over a single fiber (e.g. SMF-28 fiber). The terminal multiplexer may or may not also include a local transmit EDFA for power amplification of the 'multi-wavelength optical signal'.
2. An **intermediate line repeater** is placed approximately every 80 – 100 km to compensate for the loss of optical power as the signal travels along the fiber. The 'multi-wavelength optical signal' is amplified by an EDFA, which usually consists of several amplifier stages.
3. An **optical add-drop multiplexer**. This is a remote amplification site that amplifies the multi-wavelength signal that may have traversed up to 140 km or more before reaching the remote site. a several signals out of the 'multi-wavelength optical signal' may be removed and dropped locally.

4. A DWDM **terminal demultiplexer**. At the remote site, the terminal de-multiplexer consisting of an optical de-multiplexer and one or more 'wavelength converting transponders' separates the 'multi-wavelength optical signal' back into individual data signals and outputs them on separate fibers for client-layer systems (such as SONET/SDH). Originally, this de-multiplexing was performed entirely passively, except for some telemetry, as most SONET systems can receive 1550 nm signals,
5. **Optical Supervisory Channel (OSC)**. This is data channel which uses an additional wavelength usually outside the EDFA amplification band (at 1510 nm, 1620 nm, 1310 nm or another proprietary wavelength). The OSC carries information about the multi-wavelength optical signal as well as remote conditions at the optical terminal or EDFA site..

DWDM systems have to maintain more stable wavelength or frequency than those needed for CWDM because of the closer spacing of the wavelengths. Precision temperature control of laser transmitter is required in DWDM systems to prevent "drift" off a very narrow frequency window of the order of a few GHz.

## Wavelength converting transponders

As stated above, wavelength converting transponders served originally to translate the transmit wavelength of a client-layer signal into one of the DWDM system's internal wavelengths in the 1550 nm band (note that even external wavelengths in the 1550 nm will most likely need to be translated, as they will almost certainly not have the required frequency stability tolerances nor will it have the optical power necessary for the system's EDFA).

1R
: Retransmission. Basically, early transponders were "garbage in garbage out" in that their output was nearly an analogue 'copy' of the received optical signal, with little signal cleanup occurring. This limited the reach of early DWDM systems because the signal had to be handed off to a client-layer receiver (likely from a different vendor) before the signal deteriorated too far. Signal monitoring was basically confined to optical domain parameters such as received power.

2R
: Re-time and re-transmit. Transponders of this type were not very common and utilized a quasi-digital Schmitt-triggering method for signal clean-up. Some rudimentary signal quality monitoring was done by such transmitters that basically looked at analogue parameters.

3R
: Re-time, re-transmit, re-shape. 3R Transponders were fully digital and normally able to view SONET/SDH section layer overhead bytes such as A1 and A2 to determine signal quality health. Many systems will offer 2.5 Gbit/s transponders, which will normally mean the transponder is able to perform 3R regeneration on OC-3/12/48 signals, and possibly gigabit Ethernet, and reporting on signal health by monitoring SONET/SDH section layer overhead bytes. Many transponders will be able to perform full multi-rate 3R in both directions. Some vendors offer 10 Gbit/s transponders, which will perform Section layer overhead monitoring to all rates up to and including OC-192.

### Muxponder

The muxponder (from multiplexed transponder) has different names depending on vendor. It essentially performs some relatively simple time division multiplexing of lower rate signals into a higher rate carrier within the system (a common example is the ability to accept 4 OC-48s and then output a single OC-192 in the 1550 nm band). More recent muxponder designs have absorbed more and more TDM functionality, in some cases obviating the need for traditional SONET/SDH transport equipment.

### Reconfigurable optical add-drop multiplexer (ROADM)

As mentioned above, intermediate optical amplification sites in DWDM systems may allow for the dropping and adding of certain wavelength channels. In most systems deployed as of August 2006 this is done infrequently, because adding or dropping wavelengths requires manually inserting or replacing wavelength-selective cards. This is costly, and in some systems requires that all active traffic be removed from the DWDM system, because inserting or removing the wavelength-specific cards interrupts the multi-wavelength optical signal.

With a ROADM, network operators can remotely reconfigure the multiplexer by sending soft commands. The architecture of the ROADM is such that dropping or adding wavelengths does not interrupt the 'pass-through' channels. Numerous technological approaches are utilized for various commercial ROADMs, the trade off being between cost, optical power, and flexibility.

### Optical cross connects (OXCs)

When the network topology is a mesh, where nodes are interconnected by fibres to form an arbitrary graph, an additional fibre interconnection device is needed to route the signals from an input port to the desired output port. These devices are called optical crossconnectors (OXCs).Various categories of OXCs include electronic ("opaque"), optical ("transparent"), and wavelength selective devices.

## Enhanced WDM

Cisco's Enhanced WDM system combines 1 GB Coarse Wave Division Multiplexing (CWDM) connections using SFPs and GBICs with 10 GB Dense Wave Division Multiplexing (DWDM) connections using XENPAK, X2, or XFP DWDM modules. These DWDM connections can either be passive or boosted to allow a longer range for the connection

## Transceivers versus transponders

- *Transceivers* – Since communication over a single wavelength is one-way (simplex communication), and most practical communication systems require two-way (duplex communication) communication, two wavelengths will be required (which might or might not be on the same fiber, but typically they will be each on a separate fiber in a so-called fiber pair). As a result, at each end both a transmitter (to send a signal over a first wavelength) and a receiver (to receive a signal over a second wavelength) will be

required. A combination of a transmitter and a receiver is called a transceiver; it converts an electrical signal to and from an optical signal.There is usually types transceiver based on WDM technology.

- *Transponder* – In practice, the signal inputs and outputs will not be electrical but optical instead (typically at 1550 nm). This means that in effect we need wavelength converters instead, which is exactly what a transponder is. A transponder can be made up of two transceivers placed after each other: the first transceiver converting the 1550 nm optical signal to/from an electrical signal, and the second transceiver converting the electrical signal to/from an optical signal at the required wavelength. Transponders that don't use an intermediate electrical signal (all-optical transponders) are in development.