White Paper

Nortel Networks

WDM for Cable MSOs:

Technical Overview

Nortel Networks

Wavelength Division Multiplexing (WDM)

Multi-Service Operators (MSOs) have several technology choices available to prepare them for GbE based service delivery and the inevitable growth in digital transport bandwidth. This white paper is intended to provide an overview of Wavelength Division Multiplexing (WDM) digital transport technology choices.

Wavelength Division Multiplexing is a technology used to expand fiber optic bandwidth by enabling signals from different sources to independently travel together on a single optical fiber. Fiber capacity is increased by mapping incoming optical signals to specific light wavelengths or optical channels. With WDM, optical transmitters are equipped with 'wavelength specific' lasers attached to filters to enable the passive multiplexing of several optical signals onto a single fiber. *Figures 1* and *2* illustrate both traditional and WDM fiber optic transport technologies.

In WDM systems, each optical channel remains independent of other optical channels as if it were using its own fiber pair. Digital WDM systems enable bit rate and protocol independent access to the optical transport layer. This is crucial for metropolitan area network deployments as they eliminate the costs associated with mapping common data protocols into traditional network payloads. Each optical channel is independently multiplexed and demultiplexed at the ends of the transmission network in its original format. Therefore, different digital optical data formats utilizing different data rates can be transmitted in their native formats over the same optical fiber. For example, gigabit Ethernet, Fibre Channel, ITU-R601 optical video, DV6000, SONET, ATM, FDDI, ESCON, FICON, and other optical

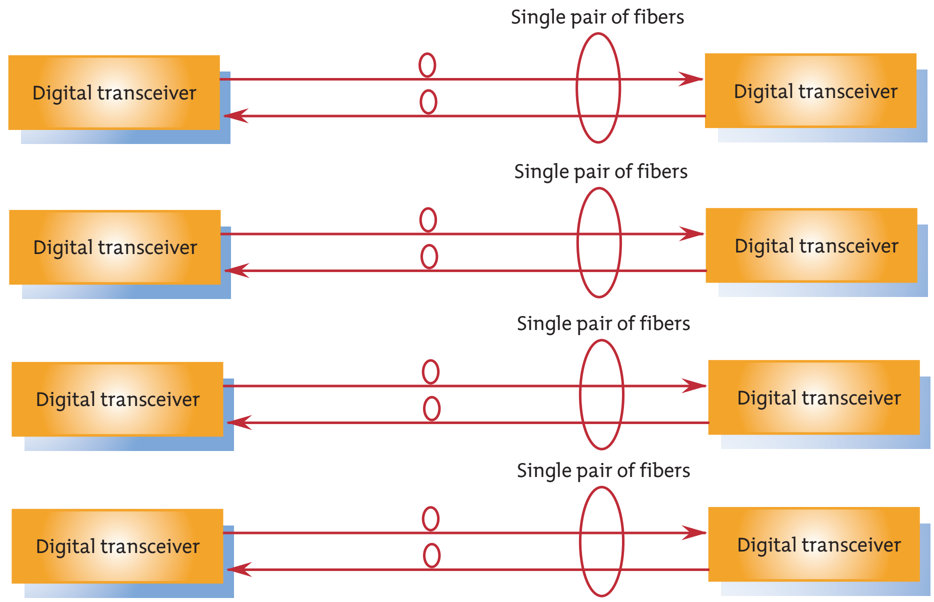


Figure 1. *Traditional digital fiber optic transport*

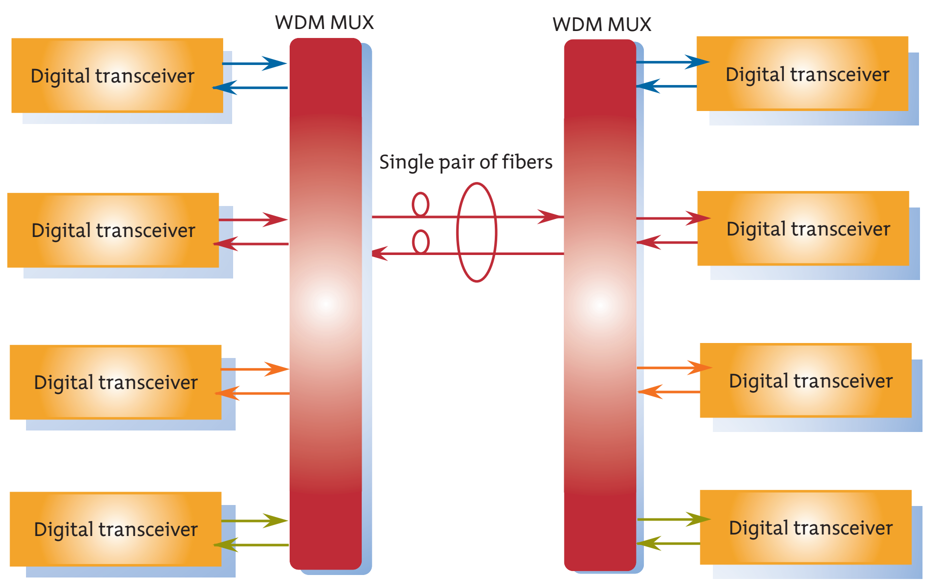


Figure 2. *Fiber optic transport using Wavelength Division Multiplexing (WDM)*

data formats can all be traveling at the same time within a single pair of optical fibers. *Figure 3* displays the bit rate and protocol independent feature of WDM technology.

WDM technology promises to solve fiber exhaust problems and eliminate the cost of converting native data into traditional digital networking formats (e.g. SONET or ATM). It is expected that WDM will be the central technology in the "all optical" networks of the future. WDM systems are being deployed today to complement existing network technologies, such as SONET and ATM, and add new capabilities for high bandwidth and native data transport.

There exist two types of WDM technologies used in networks today. These are defined as Dense Wavelength Division Multiplexing (DWDM) and Coarse Wavelength Division Multiplexing (CWDM).

Dense Wavelength Division Multiplexing (DWDM)

Dense Wavelength Division Multiplexing (DWDM), a WDM technology, is characterized by narrower optical channel spacing than Coarse WDM (CWDM). DWDM enables large channel counts within a limited spectral band—specifically the C and/or L optical bands—as supported by the spectral bandwidth amplification capability of today's optical fiber amplifier technology.

DWDM systems require precise optical mux/demux filters to provide channel spacing of 200 GHz, 100 GHz, or 50 GHz and less (i.e. approx. 1.6 nm spacing for 200 GHz systems and approximately 0.4 nm for 50 GHz spacing). Additionally, due to the narrow channel spacing and optical windows used, DWDM systems require well controlled, cooled lasers to prohibit drift outside of a given DWDM optical channel.

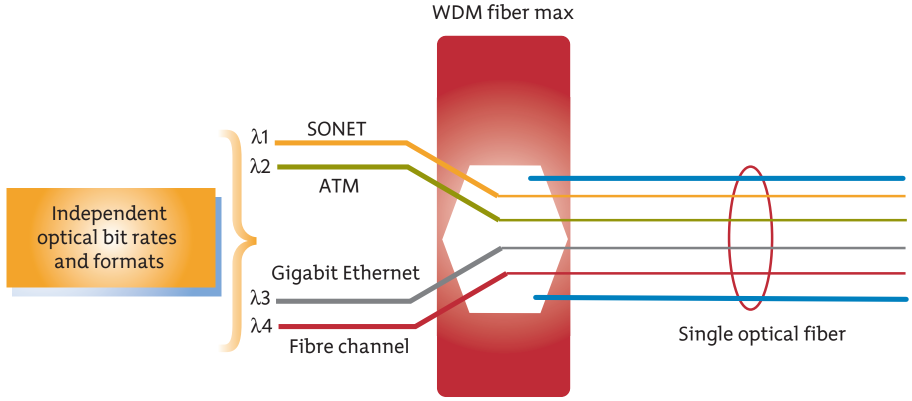


Figure 3. *Bit rate and protocol independent fiber optic access with WDM*

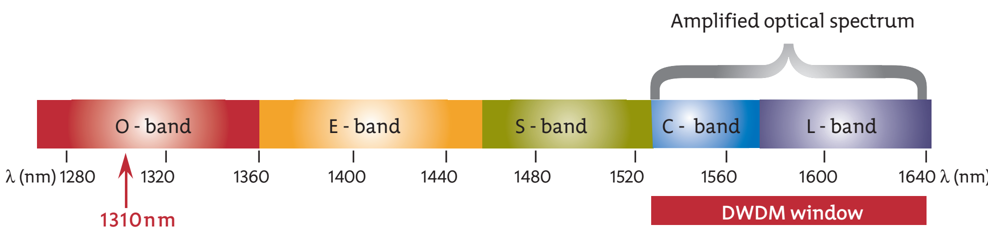


Figure 4. *Spectral amplification region of today's optical fiber amplifiers*

The objective of DWDM systems is to "squeeze" as many channels as possible into the amplified portions of optical spectrum as shown in *Figure 5.* The frequency grid for DWDM systems is defined in the ITU-T G.694.1 Recommendation.

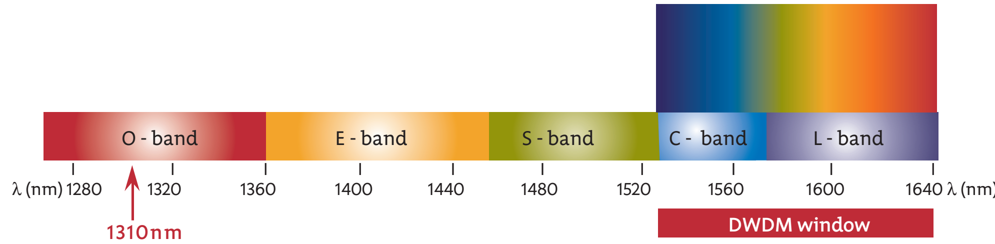


Figure 5. *DWDM C band and L band wavelength region*

By sharing the cost of amplifiers across many optical channels, DWDM becomes a very cost-effective technology for high bandwidth, multi-channel digital transport applications that require amplification to overcome distance as evidenced in long haul, regional, and metropolitan core networks.

DWDM originally gained its roots in the long haul and regional transport space. This was due to the need to maximize fiber resources as much as possible in these networks. DWDM technology was used to pack as many data channels as possible into the minimum amount of fibers. The intent was to amortize the equipment cost of DWDM systems across a very large number of data channels and maximum amount of distance. In fact, long haul DWDM systems that support up to 160 10-Gbps wavelengths over fiber distances of thousands of miles are now available. In the metro area, fiber resources were not as scarce and it wasn't until the past four or five years that DWDM became a cost-effective technology for metropolitan applications.

Introduction to Metro Digital DWDM systems

Digital DWDM systems that are specifically designed to meet the economic and technical requirements of metropolitan applications are available from several vendors. These systems are cost optimized for metro area network applications and are now being deployed by several MSOs. These systems enable the consolidation of fiber and sharing of network resources. A metropolitan digital DWDM system is characterized by lower cost per channel and typically operates over distances of up to 100 to 300 kilometers. Metro DWDM systems today can combine in excess of more than 30 separate optical channels on a single optical fiber pair.

The task of metro DWDM equipment is to accept client optical signals of varying bit rates and protocols (i.e. GbE, SONET OC-n, ATM, DV6000, PrismaDT, Fibre Channel, etc.) and provide conversion of these to ITU-T G.694.1-compliant DWDM wavelengths prior to multiplexing them together via passive DWDM filters. Most equipment can accept the client optical signals in any format on any type of fiber (i.e. 850 nm MM fiber, 1310 nm SM fiber, etc.).

Some metro DWDM equipment also provides support for sub 50 msec healing protection capability that is configurable on a per wavelength basis. Therefore, Layer 1 transport protection capabilities can be employed on optical protocols that do not offer them natively (i.e. such as PoS, Fibre Channel, and Gigabit Ethernet), resulting in increased network reliability/availability. DWDM transport elements providing the option for protection switching functionality are commonly referred to as "switched DWDM" photonic networking platforms. In addition, some of these systems perform full 3R (Retiming, Reshaping, Regeneration) functions on all client protocols to increase network resiliency. Switched DWDM systems are ideal for MSO digital transport networks that require numerous transport network connection types and configurations to satisfy the multiple traffic requirements of the MSO multiservice menu.

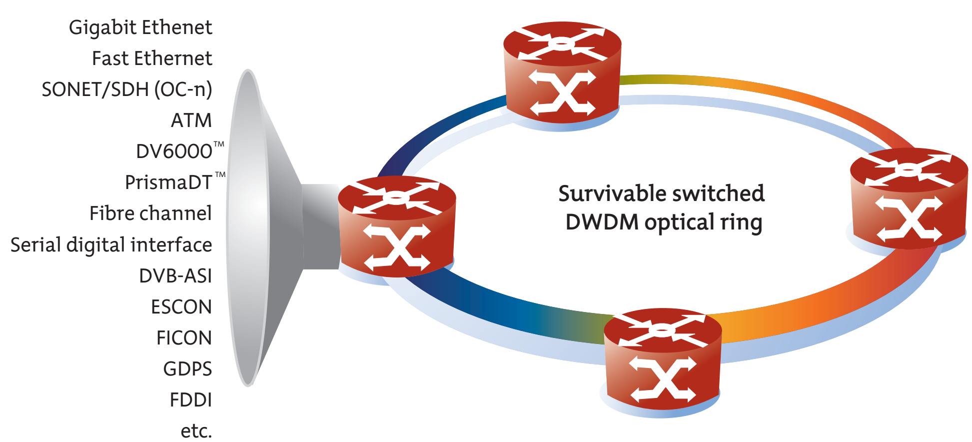


Figure 6. *Multiple native optical services over a digital DWDM transport system*

Switched DWDM network connection types

Switched DWDM transport elements were designed to complement SONET/ATM networks by providing increased capacity per fiber while leaving traditional protection switching functions to existing SONET/ATM network elements. These applications may use the unprotected connections as illustrated in *Figure 7* and *Figure 8.*

In addition, switched DWDM transport network elements were also designed to replace the SONET/ATM transport layer where appropriate. In order to be capable of both these options, 50 msec optical layer protection switching functionality can be employed as illustrated in *Figure 9.* Therefore, different options can be provisioned on the same network on a per connection (i.e. wavelength) basis.

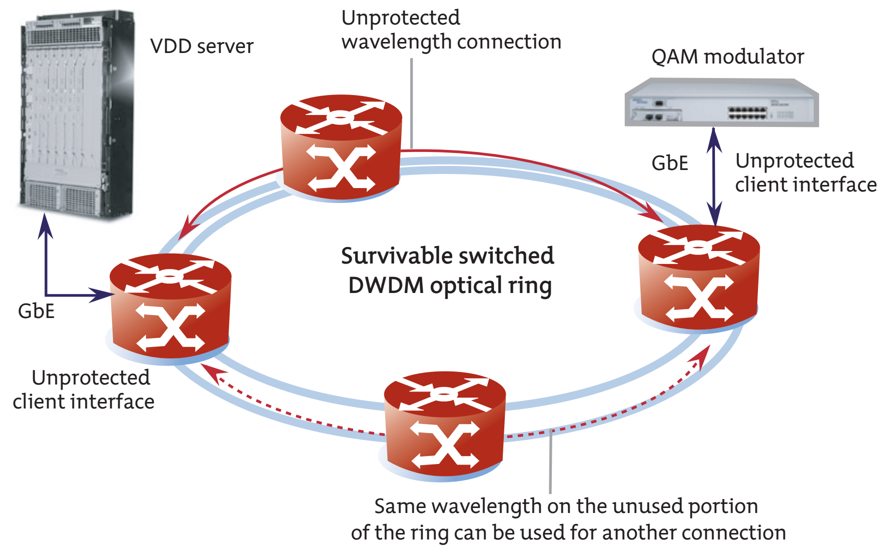


Figure 7. *Unprotected wavelength connection with unprotected client interface*

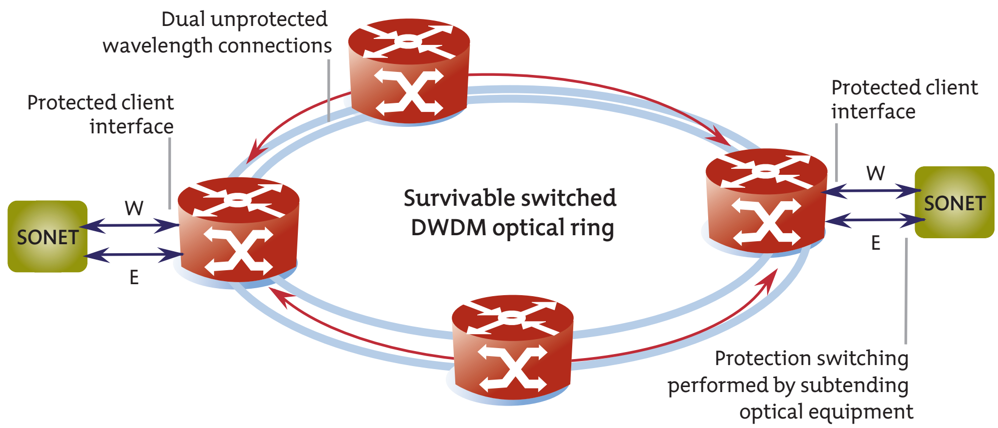


Figure 8. *Dual unprotected wavelength connections with protected client interface*

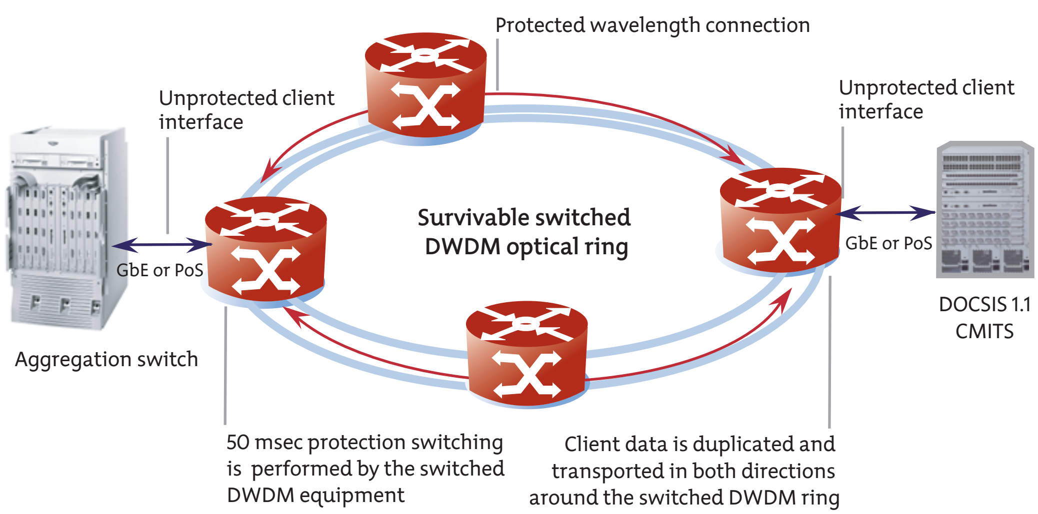


Figure 9. *Protected wavelength connections with unprotected client interface*

DWDM passive filtering and equalization

The passive DWDM filtering component is also important to consider when implementing a metro digital DWDM system. As previously stated, DWDM systems require precise optical mux/demux filters to provide channel spacings of 200 GHz, 100 GHz, or 50 GHz and less. Furthermore, metro DWDM systems can combine in excess of 30 wavelengths onto a single fiber pair. To simplify the passive portion of the DWDM system, passive filter designs typically use a "banded" approach to DWDM filtering. Typically, a DWDM band consists of three or four optical channels on a single filter and provides less optical loss than multiple, single channel filters. Banded filters are created by combining wideband group filters with fine channel filters as displayed in *Figure 10.*

By using this approach, 8 to 10 band filters are used in a system instead of 30 or more individual channel filters. Band filters provide dedicated connectivity of multiple channels between end points with a single filter. The "banded" filter approach results in less sparing requirements, simpler network design, and lower optical attenuation. Additionally, by utilizing bands of optical channels within the DWDM system, equalization of optical power levels becomes much simpler. This is especially important in ring-based DWDM designs where amplification is required. Equalization involves the adjustment of power levels entering an amplifier as shown in *Figure 11.*

As in RF systems, the input power levels to an amplifier (of all channels) should be equal or "flat", and at the proper level, to maximize amplifier performance and ensure each channel receives a proportionate degree of amplification. The same applies to optical networks.

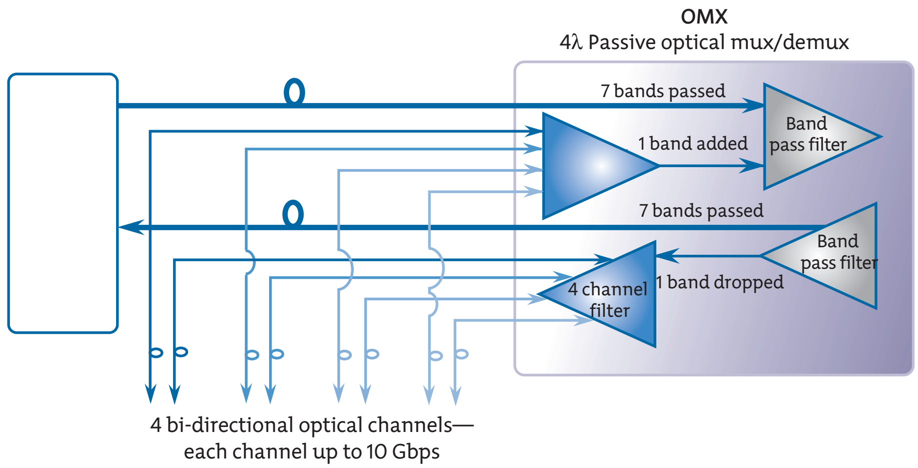


Figure 10. *Four channel DWDM band filter*

Because optical channels can have multiple different entry points into a DWDM ring, this can result in the optical wavelengths arriving at different power levels at the input to an optical amplifier station. If single channel filters are utilized, ring-based DWDM systems with amplification become extremely difficult to equalize.

DWDM network traffic configurations

Metro digital DWDM transport networks can support multiple traffic configurations such as point-to-point, hubbed, meshed, and drop + continue. These configurations are enabled through the strategic placement of the passive filter components and DWDM transport equipment. Each wavelength connection is independently configured and can differ from other wavelength connections. Therefore, metro DWDM systems can simultaneously support multiple per-wavelength traffic configurations. The optimal network configuration will be dictated by the multiservice provider's service suite and delivery requirements.

The simplest configuration is point-to-point. Passive components and DWDM equipment are placed at each end of a simple point-to-point link. The network can be grown in a "just in time" fashion by adding filters at the ends of the fiber pair and modules to the DWM equipment only when required.

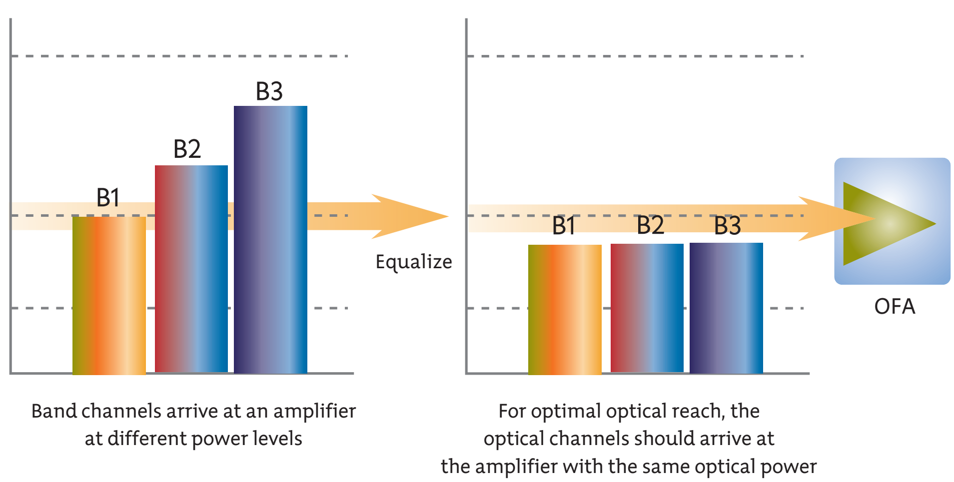


Figure 11. *DWDM band equalization*

The hubbed ring configuration is optimized for hubbed traffic flows, such as used in MSO IP/TDM access networks. East and West DWDM band filters are placed at each hub location, with each hub having access to its band only. All other optical bands not destined for a particular site are seamlessly passed through the site via the band filters. At the headend, all bands are terminated. *Figure 12* displays the traffic flows and configuration of a hubbed ring configuration.

The meshed ring configuration is targeted primarily at metropolitan interoffice and inter-hub trunking applications. Such applications use ring topologies for survivability, and can provide connections between any two points on the ring. The wavelength re-use feature of the mesh ring configuration allows SONET and/or RPR equipment to re-use the same wavelength in each span of the DWDM ring while continuing to provide network protection switching capability. The mesh connectivity capability is enabled by having the ability to locate any band filter at any point on the ring as shown in *Figure 13*. Ultimately, this enables the termination of any band at more than two places on the ring. When a band is terminated at more than two places on the ring, the ring has the ability to provide wavelength meshing.

The drop and continue configuration is targeted primarily at metropolitan point-to-multipoint applications. Such applications use ring topologies for survivability, and can provide connections between one transmit location and multiple receive locations on the same ring.

The drop and continue feature of the DWDM transport equipment allows a single location to transmit unidirectional signals in one or both directions

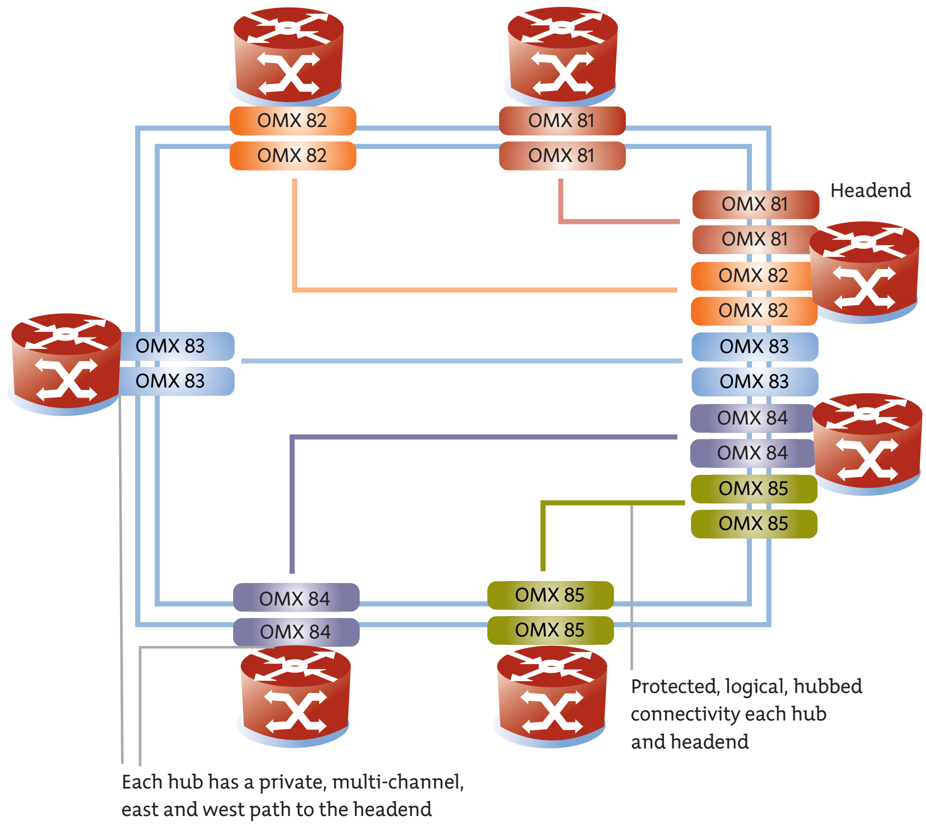


Figure 12. *DWDM hubbed ring configuration*

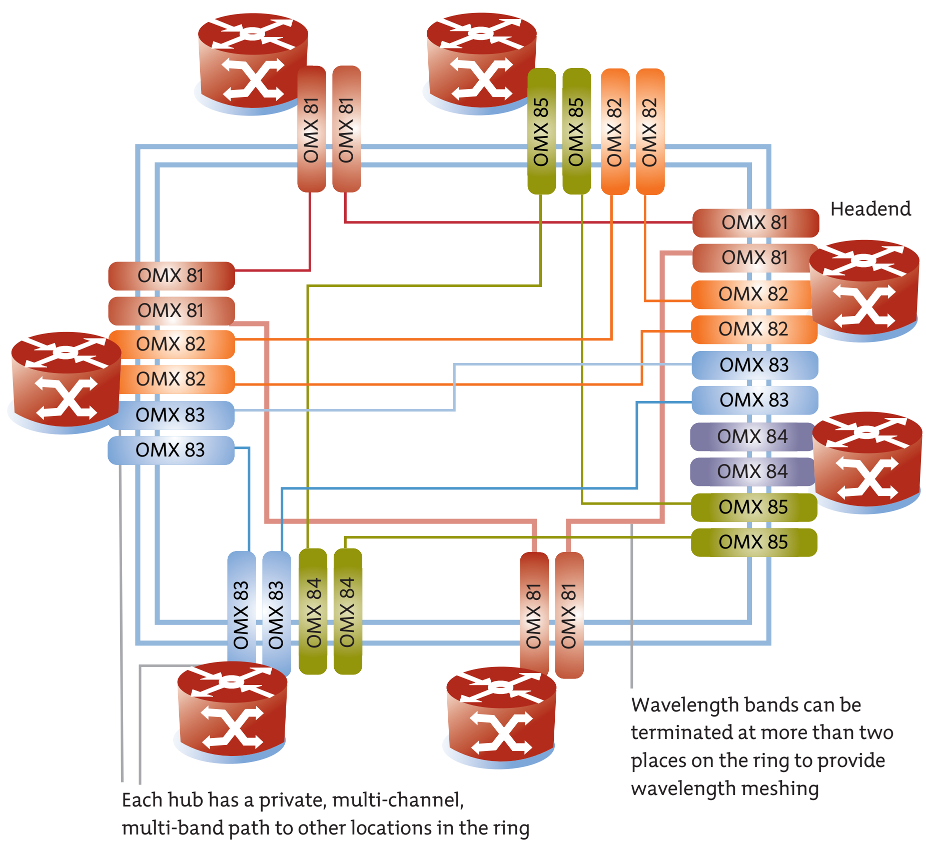


Figure 13. *Meshed ring configuration*

around the DWDM ring while using the same wavelength in each span of the ring. East and West band filters, all of the same band, are placed at each hub site and the headend. This concept is shown in *Figure 14.* This feature is particularly suited to the transport of multiple broadcast video signals (via DV6000, PrismaDT, etc.) from a single headend location to multiple primary hub locations.

DWDM wavelength monitoring

There are two predominant methods for providing DWDM wavelength and system monitoring. These include both "in-band" and "out-of-band".

In-band monitoring is typically used to provide per wavelength performance monitoring. In-band monitoring is typically enabled with per-wavelength, transparent optical service channels. These service channels are embedded as overhead into each installed wavelength and therefore do not require their own separate transmission equipment.

Out-of-band monitoring is used to collect system information from several network elements located within the ring. Typically, an out-of-band service channel (OSC) is used to communicate between DWDM sites. The OSC uses its own independent wavelength that is located outside the window used for client wavelength traffic. The OSC is used to collect overall system information such that it can be reported to higher-level management systems.

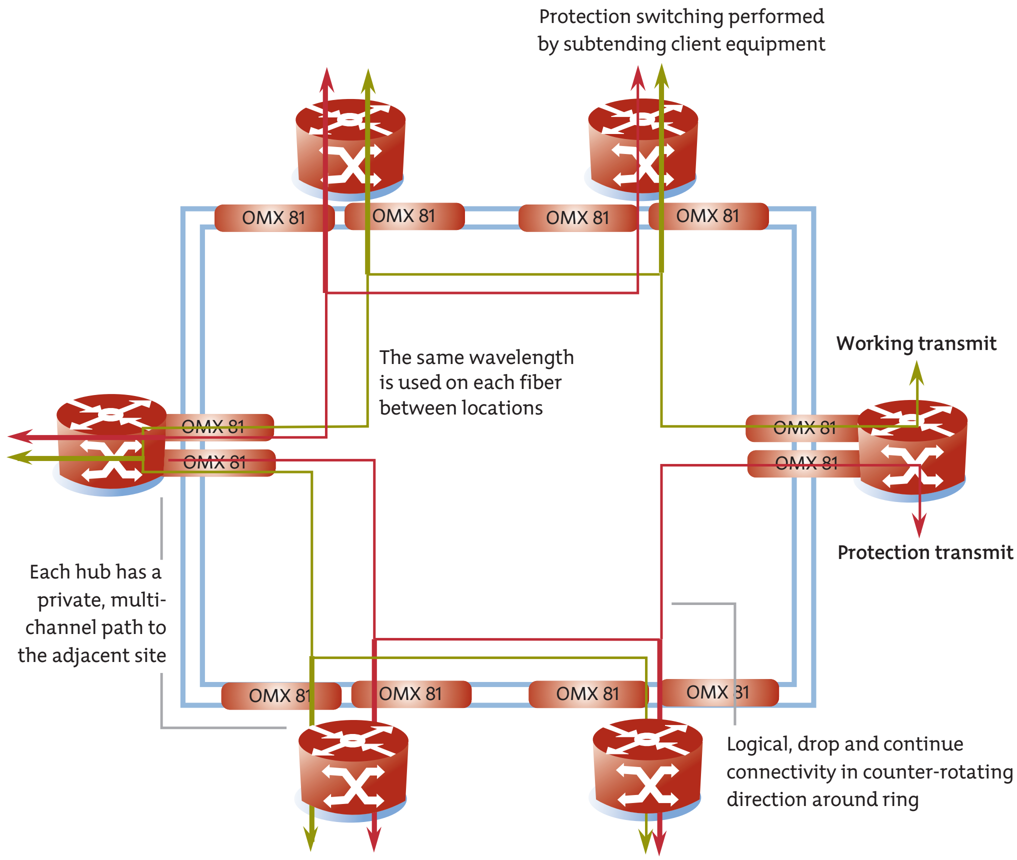


Figure 14. *DWDM drop and continue configuration*

Metropolitan DWDM benefits

Metro digital DWDM transport networks enable data traffic consolidation and simplification in the transport network layer. They provide the following benefits:

- High fiber efficiency
- Modular, "pay as you grow," scalable bandwidth capacity
- Simplified operations and management
- Allows for rapid service introduction with minimal field dispatches
- Multiple present day and future native optical services carried on a single network
- Operational efficiencies and infrastructure savings by eliminating overlay networks
- Optical layer access adaptable to any bit rate or protocol format
- Protects embedded investment… complements existing transport network equipment
- Simultaneously supports multiple per-wavelength traffic flow configurations
- Protection provisionable on a per wavelength basis with SONET-like switching capability
- Lower cost optics of subtending optical equipment
- Low latency, wire speed transport native optical protocols (GbE, Fibre channel)
- High availability and fault tolerance for mission-critical service delivery

Coarse Wavelength Division Multiplexing (CWDM)

The cost of deploying WDM technologies is directly related to the channel spacing utilized. As we have learned, DWDM systems use tight channel spacing such that amplifier cost can be shared across multiple optical channels. The drawback is that DWDM systems require more expensive laser and passive filter components.

In contrast to DWDM where the goal is to maximize transmission capacity over longer distances, Coarse Wavelength Division Multiplexing (CWDM) technology utilizes much larger wavelength spacing and is aimed at reducing network cost for unamplified, shorter distance networks. CWDM wavelength spacing has been standardized at 20 nm, which is wide enough to easily accommodate the wavelength variation of lower cost, uncooled lasers. In June of 2002, the ITU-T G.694.2 CWDM wavelength grid standard was defined and is detailed in *Figures 15* and *16.*

All of these wavelengths are usable, given appropriate choice of optical fiber (as will be discussed in the following section), although the first two (1270 and 1290 nm) are in a region of optical spectrum where Rayleigh scattering creates higher loss than elsewhere. Systems that are developed to use the entire CWDM optical spectrum, including the E band water peak region, are said to be employing "full spectrum CWDM" and offer 16 of the 18 defined wavelengths. The higher loss of the first two wavelengths is why full spectrum CWDM systems typically only offer 16 wavelengths.

ITU-T G.694.2—Nominal central wavelengths for spacing of 20 nm		
1270 nm	1290 nm	1310 nm
1330 nm	1350 nm	1370 nm
1390 nm	1410 nm	1430 nm
1450 nm	1470 nm	1490 nm
1510 nm	1530 nm	1550 nm
1570 nm	1590 nm	1610 nm

Figure 15. *ITU-T G.694.2 CWDM nominal central wavelengths*

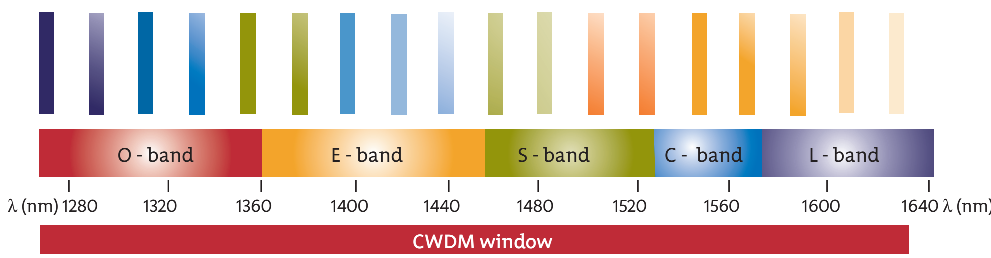


Figure 16. *Pictorial view of ITU-T G.694.2 CWDM wavelength grid*

Standard single mode fiber and CWDM: Be aware

Before any deployment of an ITU-T G.694.2-compliant CWDM system, it is critical the fiber type being used be determined. As displayed in *Figure 17,* standard single mode fiber cannot effectively support all channels in the CWDM window. Specifically, wavelengths in the upper end of the O band and all of the E band (i.e. 1350, 1370, 1390, 1410, and 1430 nm) experience very high loss due to the high attenuation "water peak" performance of standard single mode fiber.

The high water peak of standard single mode fiber is associated with the hydroxyl ion, which is a residue from moisture/water incorporated in the glass during the manufacturing process. Furthermore, this ion has also demonstrated a tendency to creep back into conventional SMF, that may have had initial low water peak loss, during the course of its useful lifetime. This loss-aging effect renders using conventional SMF, selected for low water peak loss, very risky for CWDM systems that operate over the full spectrum of CWDM channels.

As shown, G.652.C fiber (e.g. Corning Leaf, OFS Labs AllWave), also referred to as "low water peak (LWP)" or "Zero water peak (ZWP)" fiber, is specifically designed to remove the high attenuation associated with the traditional 'water' peak, thereby enabling reliable transmission of optical signals across the entire ITU-T G.694.2 CWDM wavelength grid.

Therefore, new deployments of fiber in MSO access and small distribution should take this into account if CWDM is planned for deployment over these infrastructures.

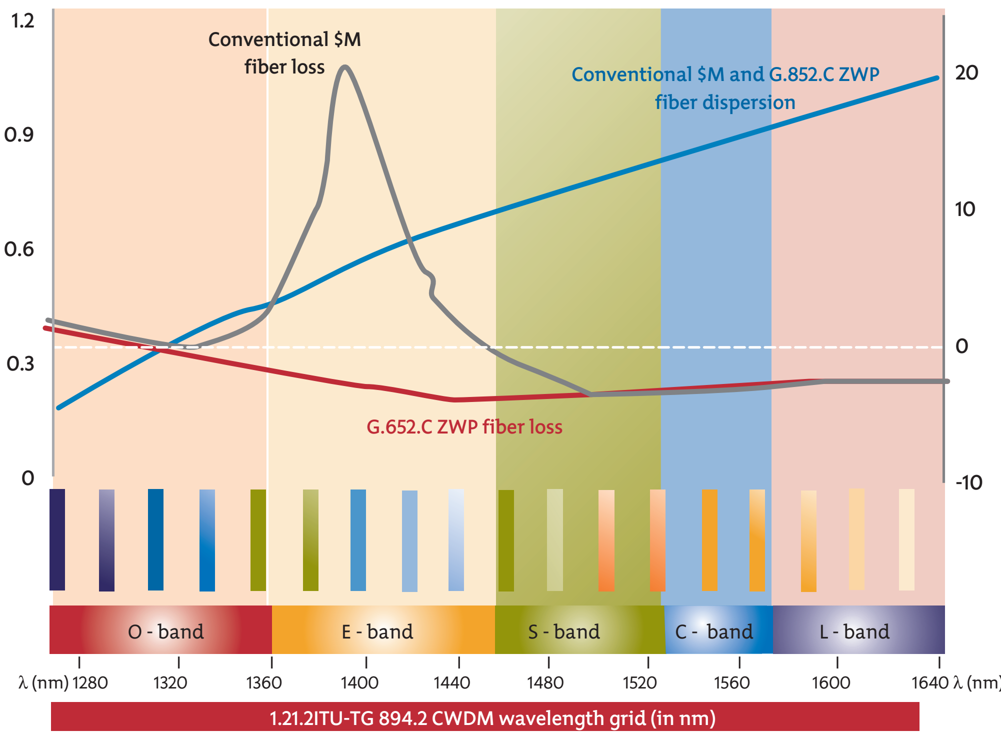


Figure 17. *Attenuation and dispersion performance of S-SMF and G.652.C ZWP fibers*

CWDM passive filtering

One of the areas that CWDM technology achieves cost benefits over DWDM is in the area of passive filtering. Because CWDM utilizes relaxed wavelength tolerances, the passive filtering component is simpler, has fewer components, and is ultimately less expensive. With CWDM, wideband group filtering is all that is required and there is no need for secondary, fine channel filtering. *Figure 18* displays a single channel CWDM filter.

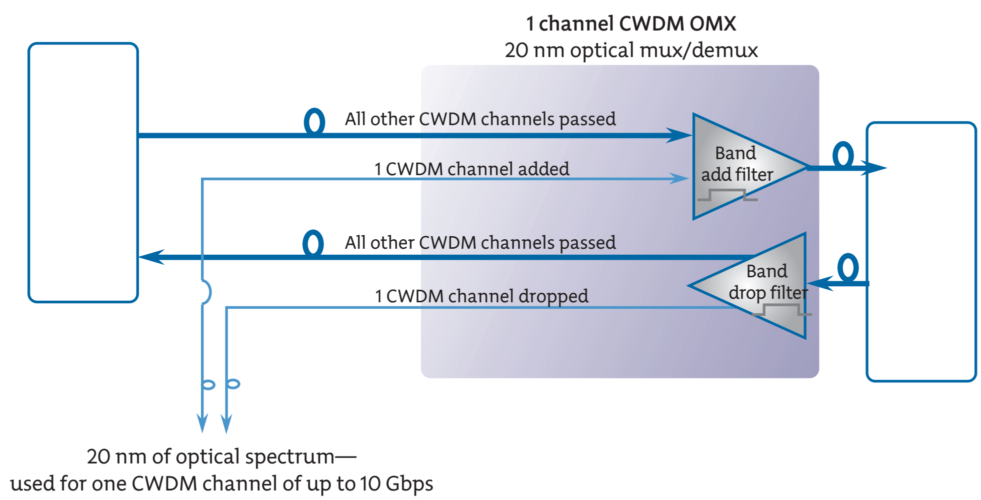


Figure 18. *Single channel CWDM passive optical mux/demux*

CWDM optical mux/demux filters are also available in 4, 8, and 16 channel granularity. As an example, *Figure 19* displays a 4 channel CWDM passive optical mux/demux filter.

Sample CWDM network equipment implementations

Many vendors that offer metro digital DWDM transport equipment also offer smaller, less expensive single or dual wavelength versions of their equipment that support CWDM implementations and provide many of the same advantages. These are designed for lower bandwidth, unamplified, WDM implementations and allow the DWDM optical transport network to be extended to the edge. These devices are attractive for low cost, small footprint, customer premises deployments in order to offer managed wavelength services as well as for smaller metro access and collector rings. *Figure 20* provides sample implementations of this approach.

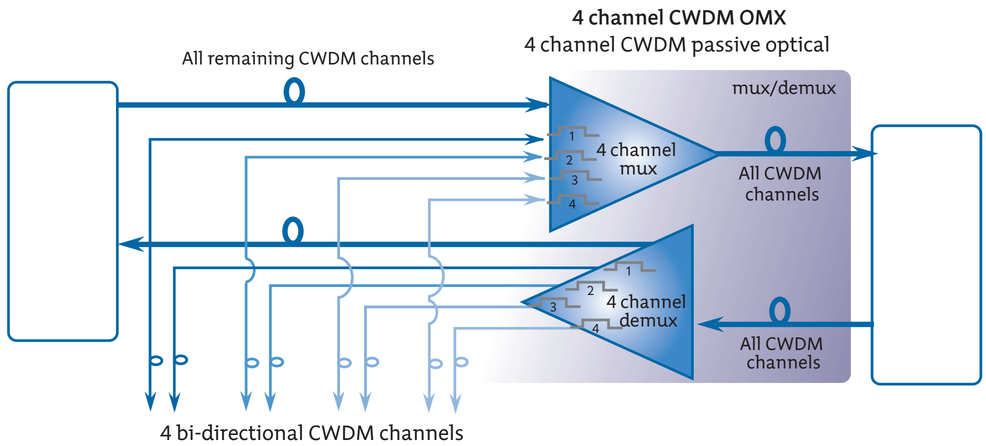


Figure 19. *Four channel CWDM passive optical mux/demux*

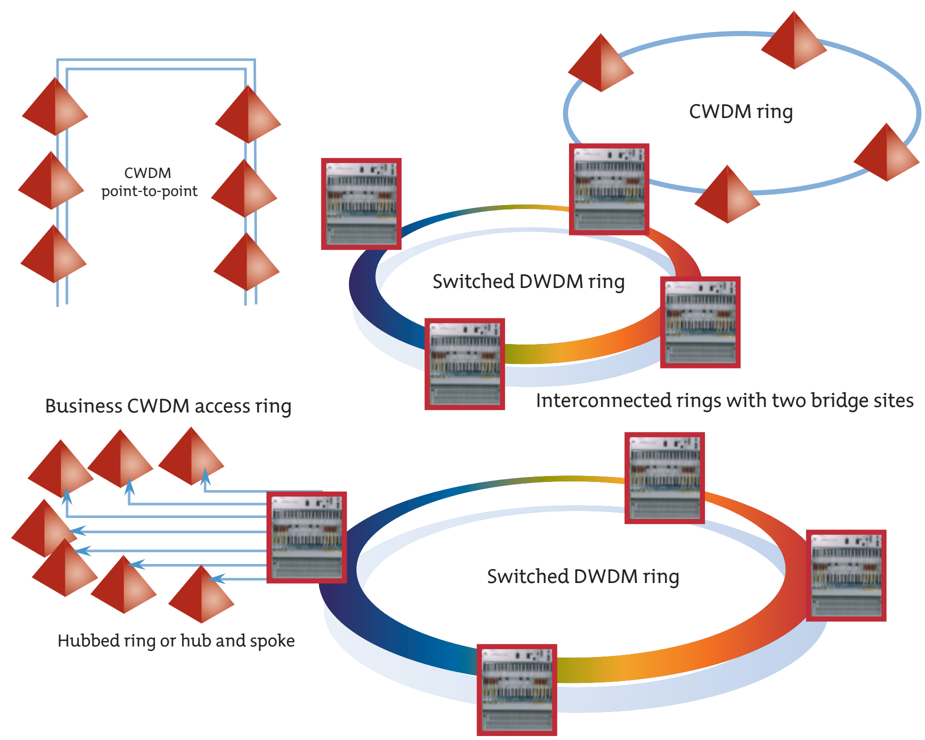


Figure 20. *Sample CWDM access ring implementations*

Figure 21 provides a more detailed look at a sample CWDM access ring implementation.

In *Figure 21,* two 4-channel CWDM filters are deployed at the headend. One is used to terminate the east fiber pair and the other is used to terminate the west fiber pair. Also at the headend is a high density equipment shelf used to terminate multiple CWDM wavelengths from both sides of the ring. At each customer site, two single channel CWDM filters are installed along with the small footprint CWDM equipment. This allows each customer site to have east and west access to its CWDM channel only while allowing all other CWDM channels to seamlessly pass through. The CWDM equipment is used to accept the client optical signal, duplicate it if protection is required, and convert to CWDM-compliant optical channels before sending it in both directions around the access ring.

As with DWDM, multiple CWDM filters can be placed throughout a network to achieve several traffic configurations such as point-to-point, hubbed, and meshed.

In addition to small footprint, protocol-independent CWDM devices as shown above, GbE optical drivers that comply with the ITU-T694.2 CWDM wavelength grid are now commercially available. These drivers are available in several form factors (e.g. GBIC, SFP) and in varying power levels so different transmission distances can be achieved. These drivers can be installed directly into today's IP routing/Ethernet switching devices to nullify the need for external transport equipment when driving Ethernet, especially GbE, from an IP router/Ethernet switch to points further in the access network. This approach is ideal for providing high-density, low-cost, GbE connectivity in the metro access network. *Figure 22* displays a point-to-point implementation of this approach.

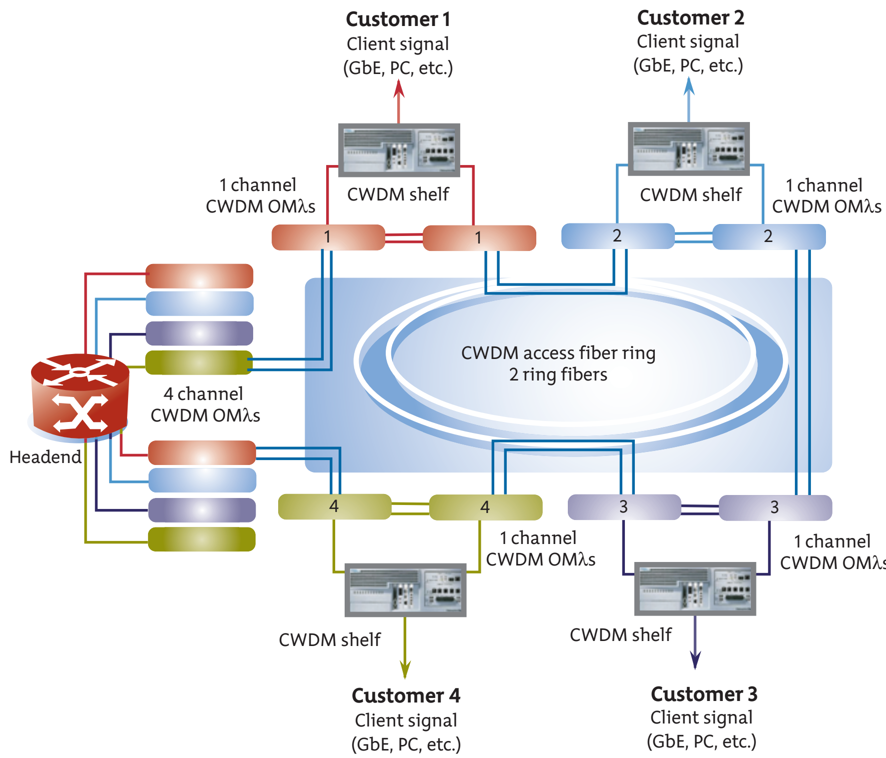


Figure 21. ***Detailed CWDM access ring implementation***

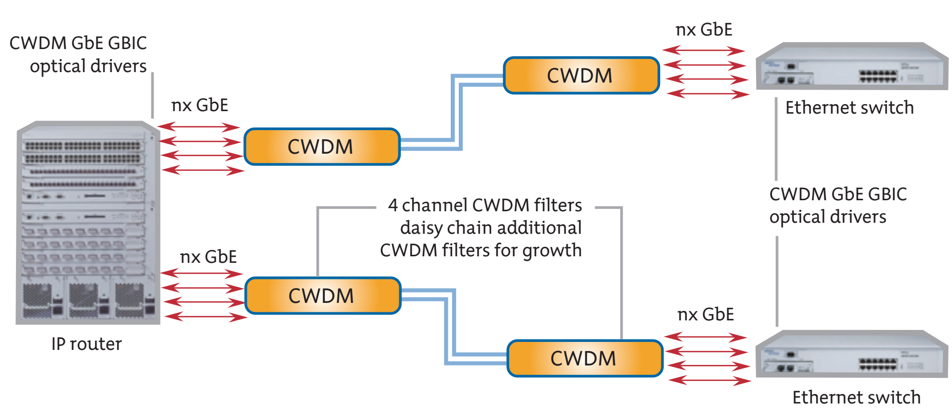


Figure 22. ***Sample point-to-point GbE-based, CWDM access network implementation***

CWDM benefits

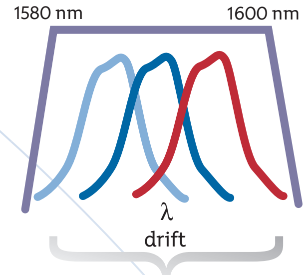
CWDM systems realize lower cost implementations through a combination of uncooled lasers, relaxed laser wavelength selection tolerances, and wide pass-band filters. In addition to being lower cost, CWDM lasers consume less power and take up less space on circuit boards when compared to their DWDM counterparts. Furthermore, CWDM passive mux/demux filters are less complex and typically lower cost than their DWDM equivalents. Therefore, CWDM systems provide a very cost-effective, WDM-based, solution for metropolitan access and shorter distance distribution networks that require less bandwidth than regional/metropolitan core networks and where optical amplification is not required. *Figure 23* highlights the advantages and limitations of CWDM technology.

CWDM advantages

- Uses lower cost, lower power, uncooled lasers due to large wavelength spacing and filter tolerance
- Can tolerate 6-8 nm of laser drift
- Lower cost passive filters (uses wideband group filtering only —no fine channel filtering required)

CWDM limitations

- Cannot achieve distances delivered by amplified DWDM systems
- Requires G.652.C low/zero water peak (LWP/ZWP) fiber to utilize all CWDM channels, standard SMF cannot effectively support 1370, 1390, 1410, 1430 nm channels



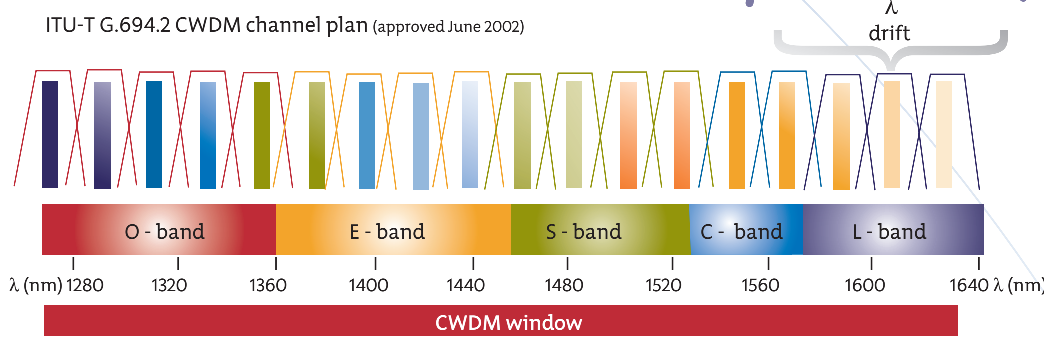


Figure 23. *Advantages and limitations of CWDM technology*

OPTera Metro 5000 Multiservice Platform

Nortel Networks offers MSOs a family of market-leading Dense Wavelength Division Multiplexing (DWDM) platforms that are an efficient means of increasing the capacity of fiber optic data transmission systems through multiplexing of multiple wavelengths of light. The OPTera Metro 5000 Multiservice Platform series increases the utilization of a single fiber strand by allowing 32 protected wavelengths of data communication traffic to be carried with 10G per wavelength scalability.

Nortel Networks DWDM portfolio of products, the OPTera Metro 5000 Multiservice Platform series, enables MSOs to cost-effectively offer their enterprise customers high-speed data services with a reduced total cost of ownership through simplified network management and ease of operation. The OPTera Metro 5000 Multiservice Platform series also serves as a new source of revenue and cost reduction for the MSOs that use the products to offer shared services.

OPTera Metro 5100 Multiservice Platform—The space-efficient OPTera Metro 5100 is a low power optical product for small bandwidth requirements serving metro primary or secondary rings and customer premises applications. It quickly and economically delivers up to eight protected wavelengths of DWDM.

OPTera Metro 5200 Multiservice Platform—The flexible OPTera Metro 5200 Multiservice Platform delivers 32 wavelengths of bandwidth through the power of DWDM and offers 10G per wavelength scalability along with a network modeling tool that simplifies the deployment and operation of efficient DWDM networks.

OPTera Metro Cabinet 5200—The free-standing OPTera Metro Cabinet 5200 is an easy-to-deploy DWDM cabinet solution that extends the OPTera Metro 5200 functionality and flexibility to metropolitan enterprise and customer premises environment applications. This cabinet delivers the benefits of the OPTera Metro 5200 Multiservice Platform in a pre-tested and pre-configured cabinet. The OPTera Metro Cabinet 5200 solution can help customers considerably reduce installation time and speed deployment.

List of acronyms

AM	Amplitude Modulation
ATM	Asynchronous Transfer Mode
BLSR	Bi-directional Line Switched Ring
BW	Bandwidth
CAP	Control Access Protocol
CAPEX	Capital Expenditure
CBR	Constant Bit Rate
CMTS	Cable Modem Termination System
CO	Central Office
CRM	Customer Relations Management
DHUB	Distribution Hub
DOCSIS	Data Over Cable System Interface Specification
DPT	Dynamic Packet Transport
DVC	Digital Video Compression
DVB-ASI	Digital Video Broadcast Asynchronous Serial Interface
DWDM	Dense Wavelength Division Multiplexing
ETSI	European Telecommunications Standardization Institute
FR	Frame Relay
GbE	Gigabit Ethernet
Gbps	Gigabits per second
GFP	Generic Framing Procedure
HDT	Host Digital Terminal
HE	Head-end
HFC	Hybrid Fiber Coaxial
IEEE	Institute of Electrical and Electronic Engineers
INM	Integrated Network Management
ISP	Internet Service Provider
IPPV	Impulse Pay Per view
IP	Internet Protocol
JIT	Just in Time
LAN	Local Area Network
MAN	Metropolitan Area Network
Mbps	Mega bits per second
MPLS	Multi Protocol Label Switching
MSO	Multiple System Operator
NE	Network Element
NEBS	Network Equipment Building System
NSG	Network Services Gateway Ethernet to QAM Converter made by Harmonic Inc.
OAM+P	Operations, Administration, Maintenance, and Provisioning
OC	Optical Carrier
PC	Personal Computer
PCM	Pulse Code Modulation
POS	Packet over SONET
PPV	Pay Per View
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QOS	Quality of Service
RF	Radio Frequency
RPD	Return Plant Demodulator
RPR	Resilient Packet Ring
SAN	Storage Area Network
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreement
SNMP	Simple Network Management Protocol
SOHO	Small Office, Home Office
SONET	Synchronous Optical Network
SRP	Spatial Re-use Protocol
STB	Set Top Box
STM	Synchronous Transfer Mode
STS	Synchronous Transport Signal
TD	Transparent Domain
TDI	Transparent Domain Identifier
TDM	Time Division Multiplexing
UNI	User to Network Interface
VLAN	Virtual Local Area Network
VOD	Video on Demand
VoIP	Voice Over Internet Protocol
VPN	Virtual Private Network
WAN	Wide Area Network

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NORTEL NETWORKS™

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