Dense Wavelength Division Multiplexing (DWDM)

Definition

Dense wavelength division multiplexing (DWDM) is a fiber-optic transmission technique that employs light wavelengths to transmit data parallel-by-bit or serial-by-character.

Overview

This tutorial addresses the importance of scalable DWDM systems in enabling service providers to accommodate consumer demand for ever-increasing amounts of bandwidth. DWDM is discussed as a crucial component of optical networks that allows the transmission of e-mail, video, multimedia, data, and voiχεο...carried in Internet protocol (IP), asynchronous transfer mode (ATM), and synchronous optical network/synchronous digital hierarchy (SONET/SDH), respectively, over the optical layer.

Topics

1. The Challenges of Today's Telecommunications Network

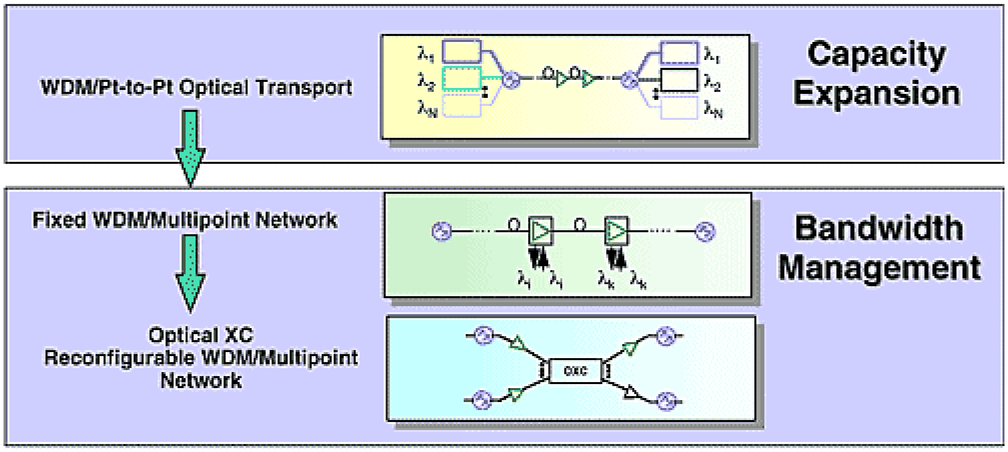
To understand the importance of DWDM and optical networking, these capabilities must be discussed in the context of the challenges faced by the telecommunications industry, and, in particular, service providers. Most U.S. networks were built using estimates that calculated bandwidth use by employing concentration ratios derived from classical engineering formulas such as Poisson and Reeling. Consequently, forecasts of the amount of bandwidth capacity needed for networks were calculated on the presumption that a given individual would only use network bandwidth six minutes of each hour. These formulas did not factor in the amount of traffic generated by Internet access (300 percent growth per year), faxes, multiple phone lines, modems, teleconferencing, and data and video transmission. Had these factors been included, a far different estimate would have emerged. In fact, today many people use the bandwidth equivalent of 180 minutes or more each hour.

Therefore, an enormous amount of bandwidth capacity is required to provide the services demanded by consumers. For perspective, in 1997, a long-distance carrier made major strides when it increased its bandwidth capacity to 1.2 Gbps (billions of bits per second) over one fiber pair. At the transmission speed of one Gbps, one thousand books can be transmitted per second. However today, if one million families decide they want to see video on Web sites and sample the new emerging video applications, then network transmission rates of terabits (trillions of bits per second [Tbps]) are required. With a transmission rate of one Tbps, it is possible to transmit 20 million simultaneous 2-way phone calls or transmit the text from 300 years–worth of daily newspapers per second.

No one could have predicted the network growth necessary to meet the demand. For example, one study estimated that from 1994 to 1998 the demand on the U.S. interexchange carriers' (IXCs') network would increase sevenfold, and for the U.S. local exchange carriers' (LECs') network, the demand would increase fourfold. In actuality, one company indicated that its network growth was 32 times that of the previous year, while another company's rate of growth in 1997 alone was the same size as its entire network in 1991. Yet another has said that the size of its network doubled every six months in that four-year period.

In addition to this explosion in consumer demand for bandwidth, many service providers are coping with fiber exhaust in their networks. An industry survey indicated that in 1995, the amount of embedded fiber already in use in the average network was between 70 percent and 80 percent. Today, many carriers are nearing one hundred–percent capacity utilization across significant portions of their networks. Another problem for carriers is the challenge of deploying and integrating diverse technologies in one physical infrastructure. Customer demands and competitive pressures mandate that carriers offer diverse services economically and deploy them over the embedded network. DWDM provides service providers an answer to that demand (see *Figure 1*).

Figure 1. Optical Transport to Optical Networking: Evolution of the Phototonics Layer



Use of DWDM allows providers to offer services such as e-mail, video, and multimedia carried as Internet protocol (IP) data over asynchronous transfer mode (ATM) and voice carried over SONET/SDH. Despite the fact that these formats—IP, ATM, and SONET/SDH—provide unique bandwidth management capabilities, all three can be transported over the optical layer using DWDM. This unifying capability allows the service provider the flexibility to respond to customer demands over one network.

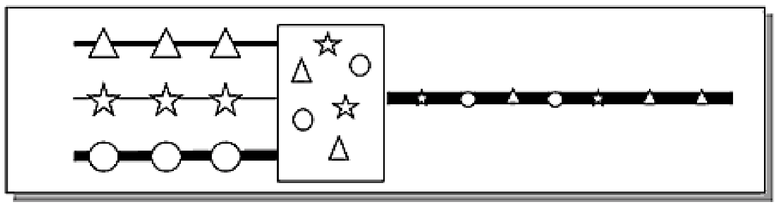
A platform that is able to unify and interface with these technologies and position the carrier with the ability to integrate current and next-generation technologies is critical for a carrier's success.

2. Resolving the Capacity Crisis

Faced with the multifaceted challenges of increased service needs, fiber exhaust, and layered bandwidth management, service providers need options to provide an economical solution. One way to alleviate fiber exhaust is to lay more fiber, and, for those networks where the cost of laying new fiber is minimal, this will prove the most economical solution. However, laying new fiber will not necessarily enable the service provider to provide new services or utilize the bandwidth management capability of a unifying optical layer.

A second choice is to increase the bit rate using time division multiplexing (TDM), where TDM increases the capacity of a fiber by slicing time into smaller intervals so that more bits (data) can be transmitted per second (see *Figure 2*). Traditionally, this has been the industry method of choice (DS–1, DS–2, DS–3, etc.). However, when service providers use this approach exclusively, they must make the leap to the higher bit rate in one jump, having purchased more capacity than they initially need. Based on the SONET hierarchy, the next incremental step from 10 Gbps TDM is 40 Gbps—a quantum leap that many believe will not be possible for TDM technology in the near future. This method has also been used with transport networks that are based on either the synchronous optical network (SONET) standard for North America or the synchronous digital network (SDH) standard for international networks.

Figure 2. Increased Network Capacity—TDM



- **Combines traffic from multiple inputs onto one common high capacity output**
- **Allows high flexibility in managing traffic; fixed bandwidth**
- **Requires electrical mux/demux function**

The telecommunications industry adopted the SONET or SDH standard to provide a standard synchronous optical hierarchy with sufficient flexibility to accommodate current and future digital signals. SONET or SDH accomplishes this by defining standard rates and formats and optical interfaces. For example, multiple electrical and optical signals are brought into a SONET terminal where they are terminated and multiplexed electrically before becoming part of the payload of an STS–1, the building block frame structure of the SONET hierarchy. The STS–1 payloads are then multiplexed to be sent out on the single fiber at a single rate: OC–3 to OC–12 to OC–48 and eventually to OC–192. SDH has a similar structure with STM–n building block resulting in signal rates of STS–1 through STM–64.

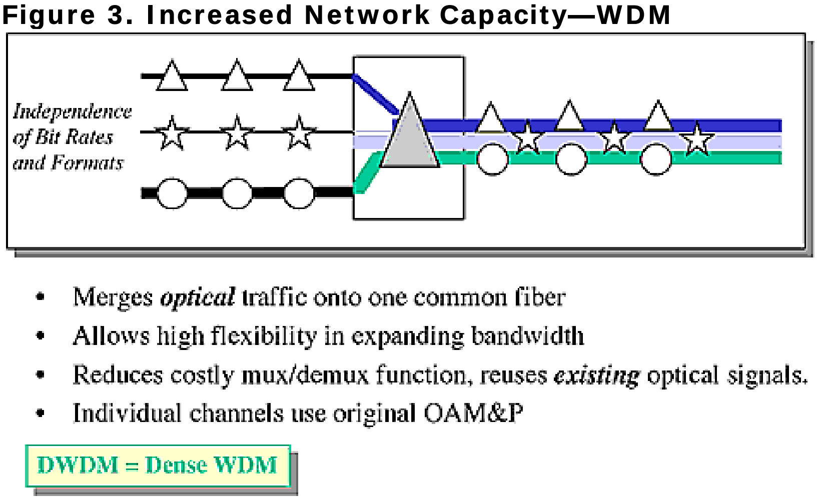
SONET and SDH, two closely related standards, provided the foundation to transform the transport networks as we know them today. They govern interface parameters; rates, formats, and multiplexing methods; and operations, administration, maintenance, and provisioning (OAM&P) for high-speed transmission of bits of information in flashing laser-light streams. A synchronous mode of transmission means that the laser signals flowing through a fiber-optic system have been synchronized to an external clock. The resulting benefit is that data streams transmitting voice, data, and images through the fiber system flow in a steady, regulated manner so that each stream of light can readily be identified and easily extracted for delivery or routing.

3. Capacity Expansion and Flexibility: DWDM

The third choice for service providers is dense wavelength division multiplexing (DWDM), which increases the capacity of embedded fiber by first assigning incoming optical signals to specific frequencies (wavelength, lambda) within a designated frequency band and then multiplexing the resulting signals out onto one fiber. Because incoming signals are never terminated in the optical layer, the interface can be bit-rate and format independent, allowing the service provider to integrate the DWDM technology easily with existing equipment in the network while gaining access to the untapped capacity in the embedded fiber.

DWDM combines multiple optical signals so that they can be amplified as a group and transported over a single fiber to increase capacity (see *Figure 3*). Each signal carried can be at a different rate (OC–3, –12, –24, etc.) and in a different format (SONET, ATM, data, etc.) For example, a DWDM network with a mix of SONET signals operating at OC–48 (2.5 Gbps) and OC–192 (10 Gbps) over a DWDM infrastructure can achieve capacities of over 40 Gbps. A system with DWDM can achieve all this gracefully while maintaining the same degree of system performance, reliability, and robustness as current transport systems—or even surpassing it. Future DWDM terminals will carry up to 80 wavelengths of OC–48, a total of 200 Gbps, or up to 40 wavelengths of OC–192, a total of 400 Gbps—which is enough capacity to transmit 90,000 volumes of an encyclopedia in one second.

Figure 3. Increased Network Capacity—WDM



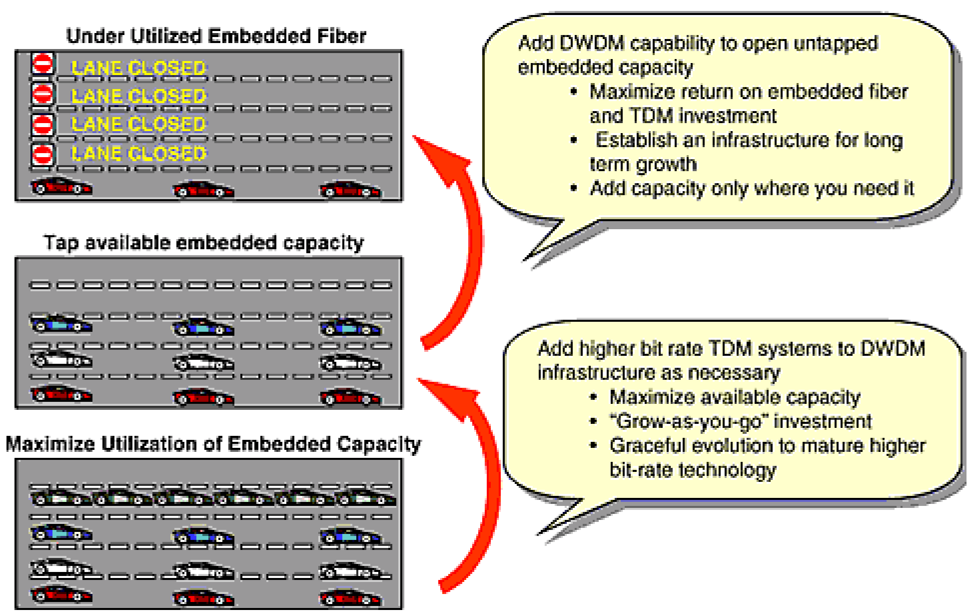
The technology that allows this high-speed, high-volume transmission is in the optical amplifier. Optical amplifiers operate in a specific band of the frequency spectrum and are optimized for operation with existing fiber, making it possible to boost lightwave signals and thereby extend their reach without converting them back to electrical form. Demonstrations have been made of ultrawideband optical-fiber amplifiers that can boost lightwave signals carrying over 100 channels (or wavelengths) of light. A network using such an amplifier could easily handle a terabit of information. At that rate, it would be possible to transmit all the world's TV channels at once or about half a million movies at the same time.

Consider a highway analogy where one fiber can be thought of as a multilane highway. Traditional TDM systems use a single lane of this highway and increase capacity by moving faster on this single lane. In optical networking, utilizing DWDM is analogous to accessing the unused lanes on the highway (increasing the number of wavelengths on the embedded fiber base) to gain access to an incredible amount of untapped capacity in the fiber. An additional benefit of optical networking is that the highway is blind to the type of traffic that travels on it. Consequently, the vehicles on the highway can carry ATM packets, SONET, and IP.

4. Capacity Expansion Potential

By beginning with DWDM, service providers can establish a grow-as-you-go infrastructure, which allows them to add current and next-generation TDM systems for virtually endless capacity expansion (see *Figure 4*). DWDM also gives service providers the flexibility to expand capacity in any portion of their networks—an advantage no other technology can offer. Carriers can address specific problem areas that are congested because of high capacity demands. This is especially helpful where multiple rings intersect between two nodes, resulting in fiber exhaust.

Figure 4. Capacity Expansion Evolution: A Strategy for the Long Term



Service providers searching for new and creative ways to generate revenue while fully meeting the varying needs of their customers can benefit from a DWDM infrastructure as well. By partitioning and maintaining different dedicated wavelengths for different customers, for example, service providers can lease individual wavelengths—as opposed to an entire fiber—to their high-use business customers.

Compared with repeater-based applications, a DWDM infrastructure also increases the distances between network elements—a huge benefit for long-distance service providers looking to reduce their initial network investments significantly. The fiber-optic amplifier component of the DWDM system enables a service provider to save costs by taking in and amplifying optical signals without converting them to electrical signals. Furthermore, DWDM allows service providers to do it on a broad range of wavelengths in the 1.55-μm region. For example, with a DWDM system multiplexing up to 16 wavelengths on a single fiber, carriers can decrease the number of amplifiers by a factor of 16 at each regenerator site. Using fewer regenerators in long-distance networks results in fewer interruptions and improved efficiency.

5. DWDM Incremental Growth

A DWDM infrastructure is designed to provide a graceful network evolution for service providers who seek to address their customers' ever-increasing capacity demands. Because a DWDM infrastructure can deliver the necessary capacity expansion, laying a foundation based on this technology is viewed as the best place to start. By taking incremental growth steps with DWDM, it is possible for service providers to reduce their initial costs significantly while deploying the network infrastructure that will serve them in the long run.

Some industry analysts have hailed DWDM as a perfect fit for networks that are trying to meet demands for more bandwidth. However, these experts have noted the conditions for this fit: a DWDM system simply must be scalable. Despite the fact that a system of OC–48 interfacing with 8 or 16 channels per fiber might seem like overkill now, such measures are necessary for the system to be efficient even two years from now.

Because OC–48 terminal technology and the related operations support systems (OSSs) match up with DWDM systems today, it is possible for service providers to begin evolving the capacity of the TDM systems already connected to their network. Mature OC–192 systems can be added later to the established DWDM infrastructure to expand capacity to 40 Gbps and beyond.

6. The Optical Layer as the Unifying Layer

Aside from the enormous capacity gained through optical networking, the optical layer provides the only means for carriers to integrate the diverse technologies of their existing networks into one physical infrastructure. DWDM systems are bit-rate and format independent and can accept any combination of interface rates (e.g., synchronous, asynchronous, OC–3, –12, –48, or –192) on the same fiber at the same time. If a carrier operates both ATM and SONET networks, the ATM signal does not have to be multiplexed up to the SONET rate to be carried on the DWDM network. Because the optical layer carries signals without any additional multiplexing, carriers can quickly introduce ATM or IP without deploying an overlay network. An important benefit of optical networking is that it enables any type of cargo to be carried on the highway.

But DWDM is just the first step on the road to full optical networking and the realization of the optical layer. The concept of an all-optical network implies that the service provider will have optical access to traffic at various nodes in the network, much like the SONET layer for SONET traffic. Optical wavelength add/drop (OWAD) offers that capability, where wavelengths are added or dropped to or from a fiber, without requiring a SONET terminal. But ultimate bandwidth management flexibility will come with a cross-connect capability on the optical layer. Combined with OWAD and DWDM, the optical cross-connect (OXC) will offer service providers the ability to create a flexible, high-capacity, efficient optical network with full optical bandwidth management. These technologies are today's reality: DWDM has been utilized in the long-distance network since 1995, OWAD will be available in products in 1998, and the first OXC was showcased at industry conventions in 1997.

7. Key DWDM System Characteristics

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. The following questions help determine whether a given DWDM system is satisfactory.

Does the system reuse embedded equipment and fiber plant?

DWDM systems at 2.5 Gbps should use the full capability of the embedded equipment and fiber base.

Is the system robust and reliable?

Well-engineered DWDM systems offer component reliability, system availability, and system margin. Although filters were often susceptible to humidity, this is no longer the case.

Do the pump lasers have connectors, or are they spliced in the optical amplifier?

An optical amplifier has two key elements: the optical fiber that is doped with the element erbium and the amplifier. When a pump laser is used to energize the erbium with light at a specific wavelength, the erbium acts as a gain medium that amplifies the incoming optical signal. If a connector is used rather than a splice, slight amounts of dirt on the surface may cause the connector to become damaged.

Is manual intervention required when adding or removing channels?

Automatic adjustment of the optical amplifiers when channels are added or removed achieves optimal system performance. This is important because if there is just one channel on the system with high power, degradation in performance through self-phase modulation can occur. On the other hand, too little power results in not enough gain from the amplifier.

Does the system use fluoride- or silica-based fiber amplifiers?

In the 1530- to 1565-nm range, silica-based optical amplifiers with filters and fluoride-based optical amplifiers perform equally well. However, fluoride-based optical amplifiers are intrinsically more costly to implement. The long-term reliability of fluoride-based fibers has not yet been verified.

Can the system's number of wavelengths and bit rate be upgraded?

While the answer is yes for all DWDM systems, planning for this is critical. If service providers put together their networks in a specific way and then want to upgrade, one of two things must happen: They need either more power or additional signal-to-noise margin. For example, each time providers double the number of channels or the bit rate, 3 dB of additional signal-to-noise margin is needed.

Does the system offer standards-compliant maintenance interfaces?

Standard transaction language 1 interfaces are widely available for DWDM systems. Interfaces should readily fit into a service provider's typical maintenance scheme.

8. Conclusion

Optical networking provides the backbone to support existing and emerging technologies with almost limitless amounts of bandwidth capacity. All-optical networking (not just point-to-point transport) enabled by optical cross-connects, optical programmable add/drop multiplexers, and optical switches provides a unified infrastructure capable of meeting the telecommunications demands of today and tomorrow. Transparently moving trillions of bits of information efficiently and cost-effectively will enable service providers to maximize their embedded infrastructure and position themselves for the capacity demand of the next millennium.

Self-Test

1. ________ (DWDM) is a _______ transmission technique.

    a. Dense wavelength division multiplexing; fiber-optic

    b. Direct wavelength directing medium; telecommunications

    c. Direct wave division multiplexing; fiber-optic

    d. none of the above

2. DWDM allows the transmission of _______ over the optical layer.

    a. voice and e-mail

    b. multimedia and video

    c. data

    d. none of the above

e. all of the above

3. DWDM enables different formats, such as ______, to be transmitted over the optical layer.

    a. IP and ATM

    b. ATM and SONET

    c. SONET and SDH

    d. SDH and ATM

    e. all of the above

4. DWDM increases the capacity of _____ fiber by first assigning incoming ________ to specific frequencies within a designated frequency band and then _______ the resulting signals out onto one fiber.

    a. optical fiber; wavelengths; combining

    b. embedded; optical signals; multiplexing

    c. group; signals; multiplexing

    d. dense; wavelengths; multiplexing

5. Future DWDM terminals will have the capacity to transmit ____ volumes of an encyclopedia in one second.

    a. 90

    b. 250

    c. 1, 500

    d. 90,000

6. Compared with repeater-based applications, a DWDM infrastructure also increases the distances between network elements—a huge benefit for long-distance service providers looking to significantly reduce their initial network investments.

    a. true

    b. false

7. One drawback to DWDM is that its infrastructure is not easily expanded.

   a. true

   b. false

8. DWDM systems are bit-rate and format independent and can accept any combination of interface rates on the same fiber at the same time.

   a. true

   b. false

9. DWDM is the final step on the road to full optical networking and the realization of the optical layer.

   a. true

   b. false

10. Standard transaction language 1 interfaces are widely available for DWDM systems.

   a. true

   b. false

Correct Answers

1. ________ (DWDM) is a _______ transmission technique.

   a. Dense wavelength division multiplexing; fiber-optic

   b. Direct wavelength directing medium; telecommunications

   c. Direct wave division multiplexing; fiber-optic

   d. none of the above

   See Definition.

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See Overview.

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   c. SONET and SDH

   d. SDH and ATM

   e. all of the above

   See Topic 1.

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   b. embedded; optical signals; multiplexing

   c. group; signals; multiplexing

   d. dense; wavelengths; multiplexing

   See Topic 3.

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See Topic 3.

6. Compared with repeater-based applications, a DWDM infrastructure also increases the distances between network elements—a huge benefit for long-distance service providers looking to significantly reduce their initial network investments.

   a. true

   b. false

   See Topic 4.

7. One drawback to DWDM is that its infrastructure is not easily expanded.

   a. true

   b. false

   See Topic 5.

8. DWDM systems are bit-rate and format independent and can accept any combination of interface rates on the same fiber at the same time.

   a. true

   b. false

   See Topic 6.

9. DWDM is the final step on the road to full optical networking and the realization of the optical layer.

   a. true

   b. false

   See Topic 6.

10. Standard transaction language 1 interfaces are widely available for DWDM systems.

    a. true

    b. false

    See Topic 7.

Glossary

ATM
asynchronous transfer mode

DWDM
dense wavelength division multiplexing

IEC
interexchange carrier

IP
Internet protocol

LEC
local exchange carrier

OAM&P
operations, administration, maintenance, and provisioning

OWAD
optical wavelength add/drop

OXC
optical cross-connect

SDH
synchronous digital hierarchy

SONET
synchronous optical network

TDM
time division multiplexing