Chapter 5

DWDM

Overview of DWDM

Definition

Dense wavelength division multiplexing (DWDM) is a fiber-optic transmission technique that employs multiple light wavelengths to transmit data in parallel through a single fiber.

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 a crucial component of optical networks that allows the transmission of e-mail, video, multimedia, data, and voice—carried in different formats like Internet protocol (IP), asynchronous transfer mode (ATM), and synchronous digital hierarchy (SDH), respectively, over the optical layer.

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. The 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. 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. 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 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.

In addition to this explosion in consumer demand for bandwidth, many service providers are coping with fiber exhaust in their networks. Today, many operators are nearing one hundred–percent capacity utilization across significant portions of their networks. Another problem for operators 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.

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 SDH. Despite the fact that these format—IP, ATM, and 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.

Resolving the Capacity Crisis

Faced with the 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, this will not be 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), so that more bits (data) can be transmitted per second. Traditionally, this has been the industry method of choice (STM–1, STM –4, STM –16, 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 SDH hierarchy, the next incremental step from 10 Gbps TDM is 40 Gbps—a quantum leap that may remain unutilized in the near future.

The telecommunications industry adopted the SDH standard to provide a standard synchronous optical hierarchy with sufficient flexibility to accommodate current and future digital signals. SDH accomplishes this by defining standard rates and formats and optical interfaces. For example, multiple electrical and optical signals are brought into a SDH terminal where they are terminated and multiplexed electrically before becoming part of the payload of an STM–1, the building block frame structure of the SDH hierarchy. The STM–1 payloads are then multiplexed to be sent out on the single fiber at a single rate: STM-4 to STM-16 to STM-64 and eventually to STM-256.

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.

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 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. Each signal carried can be at a different rate and in a different format (SDH, ATM, data, etc.) For example, a DWDM network with a mix of SDH signals operating at 2.5 Gbps and 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. Today we are talking of DWDM terminals of up to 80 wavelengths of STM-16, a total of 200 Gbps, which is enough capacity to transmit 40,000 volumes of an encyclopedia in one second.

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, making it possible to boost light wave signals and thereby extend their reach without converting them back to electrical form. Demonstrations have been made of ultra wideband optical-fiber amplifiers that can boost light wave 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. So, the vehicles on the highway can carry ATM packets, SDH, and IP.

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. 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.

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 1.55µm 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.

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, STM-1, STM-4, STM-16 etc) on the same fiber at the same time. If a carrier operates both ATM and SDH networks, the ATM signal does not have to be multiplexed up to the SDH 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.

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 SDH layer for SDH traffic. Optical wave-length add/drop (OADM) offers that capability, where wavelengths are added or dropped to or from a fiber, without requiring a SDH terminal. But ultimate bandwidth management flexibility will come with a cross-connect capability on the optical layer. Combined with OADM 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.

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.

a. Well-engineered DWDM systems offer component reliability, system availability, and system margin.
b. 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.
c. 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.
d. 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.
e. It is possible to upgrade the channel capacity or wavelengths. However, for this 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.

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.

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