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DWDM: An Innovation in Optical Communication

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ABSTRACT: In today's world, demand for bandwidth is driven largely by new data applications, Internet usage, and growth in wireless communications. In response to this explosive growth in bandwidth demand, along with the emergence of IP as the common foundation for all services, long-haul service providers are moving away from TDM based systems, which were optimized for voice but now prove to be costly and inefficient. This paper discuss the fundamentals of wavelength division multiplexing in fiber optic telecommunications, which is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths of laser light to carry different signals. This allows for a multiplication in capacity, in addition to making it possible to perform bidirectional communications over one strand of fiber. This paper discuss about the increased need of carrier bandwidth, some possibilities to increase it and comparisons of TDM and WDM. It also discusses dense wavelength division multiplexing (DWDM) as an important innovation in optical networks and the benefits it can provide in optical communication.

KEYWORDS *:* WDM, DWDM,SONET, MANs, regenerators.

1. INTRODUCTION

As we enter the twenty-first century, it goes without saying that information services have permeated society and commerce. Information, while still a tool, has become a commodity in itself. Yet the universal acceptance and ubiquitous adoption of information technology systems has strained the backbones on which they were built. High demand—coupled with high usage rates, a deregulated telecommunications environment, and high availability requirements—is rapidly depleting the capacities of fibers that, when installed 10 years ago, were expected to suffice for the foreseeable future.

The explosion in demand for network bandwidth is largely due to the growth in data traffic, specifically Internet Protocol (IP). Leading service providers report bandwidths doubling on their backbones about every six to nine months. This is largely in response to the 300 percent growth per year in Internet traffic, while traditional voice traffic grows at a compound annual rate of only about 13 percent (see Fig 1-1).

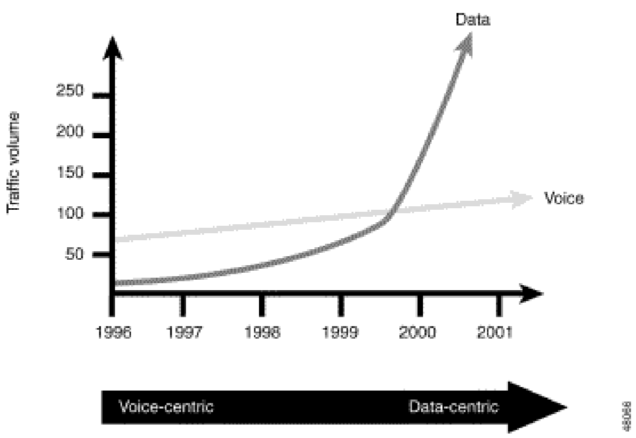

Figure 1-1: Data Traffic Overtakes Voice Traffic

At the same time that network traffic volume is increasing, the nature of the traffic itself is becoming more complex. Traffic carried on a backbone can originate as circuit based (TDM voice and fax), packet based (IP), or cell based

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(ATM and frame relay). In addition, there is an increasing proportion of delay sensitive data, such as voice over IP and streaming video.

In response to this explosive growth in bandwidth demand, along with the emergence of IP as the common foundation for all services, long-haul service providers are moving away from TDM based systems, which were optimized for voice but now prove to be costly and inefficient. Meanwhile, metropolitan networks are also experiencing the impact of growing congestion, as well as rapidly changing requirements that call for simpler and faster provisioning than is possible with older equipment and technologies.

II. COMPETITION AND RELIABILITY

While the demand for bandwidth is driven largely by new data applications, Internet usage, and the growth in wireless communications, two additional factors come into play: competition and network availability.

The telecommunication sector, long a beneficiary of government regulation, is now a highly competitive industry. Competition was first introduced into the U.S. long-distance market in 1984, and the 1996 Telecommunications Reform Act is now resulting in an increasingly broad array of new operators. These new carriers are striving to meet the new demand for additional services and capacity.

There are two main effects on the industry from competition:

- Enhanced services are created by newcomers trying to compete with incumbents. In the metropolitan market, for example, there are broadband wireless and DSL services to homes and small and medium-sized business, high-speed private line and VPN services to corporations, and transparent LAN services to enterprise network customers.

- New carriers coming onto the scene create new infrastructure so that they do not have to lease from existing operators. Using this strategy, they have more control over provisioning and reliability.

As telecommunications and data services have become more critical to business operations, service providers have been required to ensure that their networks are fault tolerant. To meet these requirements, providers have had to build backup routes, often using simple 1:1 redundancy in ring or point-to-point configurations. Achieving the required level of reliability, however, means reserving dedicated capacity for failover. These can double the need for bandwidth on an already strained infrastructure (see Figure 1-2).

3. Options for Increasing Carrier Bandwidth

Faced with the challenge of dramatically increasing capacity while constraining costs, carriers have two options: Install

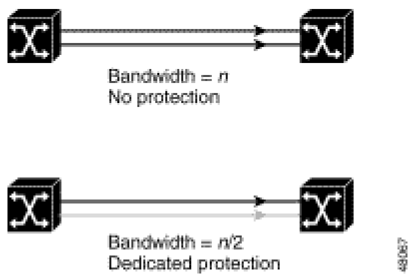

Figure 1-2: Reserving Bandwidth Reduces Overall Capacity

new fiber or increase the effective bandwidth of existing fiber. Laying new fiber is the traditional means used by carriers to expand their networks. Deploying new fiber, however, is a costly proposition. It is estimated at about $70,000 per mile, most of which is the cost of permits and construction rather than the fiber itself. Laying new fiber may make sense only when it is desirable to expand the embedded base.

Increasing the effective capacity of existing fiber can be accomplished in two ways:

- Increase the bit rate of existing systems.
- Increase the number of wavelengths on a fiber.

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3.1 Increase the Bit Rate

Using TDM, data is now routinely transmitted at 2.5 Gbps (OC-48) and, increasingly, at 10 Gbps (OC-192); recent advances have resulted in speeds of 40 Gbps (OC-768). The electronic circuitry that makes this possible, however, is complex and costly, both to purchase and to maintain. In addition, there are significant technical issues that may restrict the applicability of this approach. Transmission at OC-192 over single-mode (SM) fiber, for example, is 16 times more affected by chromatic dispersion than the next lower aggregate speed, OC-48. The greater transmission power required by the higher bit rates also introduces nonlinear effects that can affect waveform quality. Finally, polarization mode dispersion, another effect that limits the distance a light pulse can travel without degradation, is also an issue.

3.2 Increase the Number of Wavelengths

In this approach, many wavelengths are combined onto a single fiber. Using wavelength division multiplexing (WDM) technology several wavelengths, or light colors, can simultaneously multiplex signals of 2.5 to 40 Gbps each over a strand of fiber. Without having to lay new fiber, the effective capacity of existing fiber plant can routinely be increased by a factor of 16 or 32. Systems with 128 and 160 wavelengths are in operation today, with higher density on the horizon.

IV. WAVELENGTH DIVISION MULTIPLEXING

WDM increases the carrying capacity of the physical medium (fiber) using a completely different method from TDM. WDM assigns incoming optical signals to specific frequencies of light (wavelengths, or lambdas) within a certain frequency band. This multiplexing closely resembles the way radio stations broadcast on different wavelengths without interfering with each other (see Figure 1-3). Because each channel is transmitted at a different frequency, we can select from them using a tuner. Another way to think about WDM is that each channel is a different color of light; several channels then make up a "rainbow."

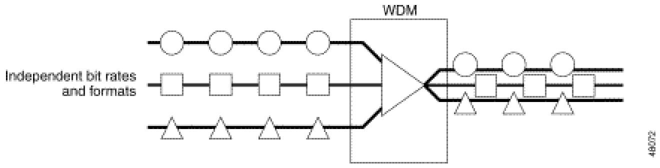

Figure 1-3: Increasing Capacity with WDM

In a WDM system, each of the wavelengths is launched into the fiber, and the signals are demultiplexed at the receiving end. Like TDM, the resulting capacity is an aggregate of the input signals, but WDM carries each input signal independently of the others. This means that each channel has its own dedicated bandwidth; all signals arrive at the same time, rather than being broken up and carried in time slots.

The difference between WDM and dense wavelength division multiplexing (DWDM) is fundamentally one of only degree. DWDM spaces the wavelengths more closely than does WDM, and therefore has a greater overall capacity. The limits of this spacing are not precisely known, and have probably not been reached, though systems are available in mid-year 2000 with a capacity of 128 lambdas on one fiber. DWDM has a number of other notable features. These include the ability to amplify all the wavelengths at once without first converting them to electrical signals, and the ability to carry signals of different speeds and types simultaneously and transparently over the fiber (protocol and bit rate independence).

4.1 TDM and WDM Compared

SONET TDM takes synchronous and asynchronous signals and multiplexes them to a single higher bit rate for transmission at a single wavelength over fiber. Source signals may have to be converted from electrical to optical or from optical to electrical and back to optical before being multiplexed. WDM takes multiple optical signals, maps them to individual wavelengths, and multiplexes the wavelengths over a single fiber. Another fundamental difference between the two technologies is that WDM can carry multiple protocols without a common signal format, while SONET cannot. Some of the key differences between TDM and WDM are graphically illustrated in Figure 1-4.

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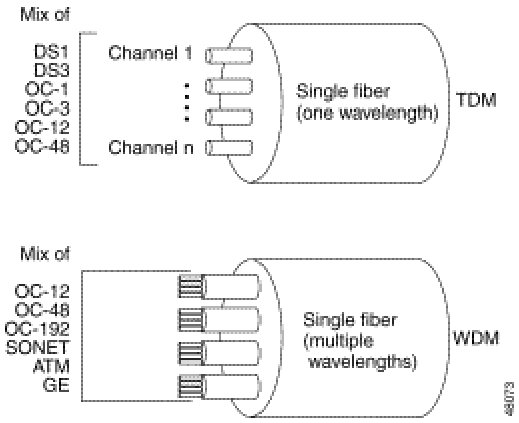

Figure 1-4: TDM and WDM Interfaces

V. VALUE OF DWDM IN THE METROPOLITAN AREA

DWDM is the clear winner in the backbone. It was first deployed on long-haul routes in a time of fiber scarcity. Then the equipment savings made it the solution of choice for new long-haul routes, even when ample fiber was available. While DWDM can relieve fiber exhaust in the metropolitan area, its value in this market extends beyond this single advantage. Alternatives for capacity enhancement exist, such as pulling new cable and SONET overlays, but DWDM can do more. What delivers additional value in the metropolitan market is DWDM's fast and flexible provisioning of protocol- and bit rate-transparent, data-centric, protected services, along with the ability to offer new and higher-speed services at less cost.

The need to provision services of varying types in a rapid and efficient manner in response to the changing demands of customers is a distinguishing characteristic of the metropolitan networks. With SONET, which is the foundation of the vast majority of existing MANs, service provisioning is a lengthy and complex process. Network planning and analysis, ADM provisioning, Digital Crossconnect System (DCS) reconfiguration, path and circuit verification, and service creation can take several weeks. By contrast, with DWDM equipment in place provisioning new service can be as simple as turning on another lightwave in an existing fiber pair.

Potential providers of DWDM-based services in metropolitan areas, where abundant fiber plant already exists or is being built, include incumbent local exchange carriers (ILECs), competitive local exchange carriers (CLECs), inter-exchange carriers (IXCs), Internet service providers (ISPs), cable companies, private network operators, and utility companies. Such carriers can often offer new services for less cost than older ones. Much of the cost savings is due to reducing unnecessary layers of equipment, which also lowers operational costs and simplifies the network architecture.

Carriers can create revenue today by providing protocol-transparent, high-speed LAN and SAN services to large organizations, as well as a mixture of lower-speed services (Token Ring, FDDI, Ethernet) to smaller organizations. In implementing an optical network, they are ensuring that they can play in the competitive field of the future.

VI. REQUIREMENTS IN THE METROPOLITAN AREA

The requirements in the metropolitan market may differ in some respects from those in the long-haul network market, yet metropolitan networks are still just a geographically distinguished segment of the global network. What happens in the core must be supported right to the edge. IP, for example, is the dominant traffic type, so interworking with this layer is a requirement, while not ignoring other traffic (TDM). Network management is now of primary concern, and protection schemes that ensure high availability are a given.
Key requirements for DWDM systems in the MAN include the following:

- Multiprotocol support
- Scalability
- Reliability and availability
- Openness (interfaces, network management, standard fiber types, electromagnetic compatibility)
- Ease of installation and management
- Size and power consumption

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- Cost effectiveness

VII. MERITS OF DWDM

From both technical and economic perspectives, the ability to provide potentially unlimited transmission capacity is the most obvious advantage of DWDM technology. The current investment in fiber plant can not only be preserved, but optimized by a factor of at least 32. As demands change, more capacity can be added, either by simple equipment upgrades or by increasing the number of lambdas on the fiber, without expensive upgrades. Capacity can be obtained for the cost of the equipment, and existing fiber plant investment is retained.
Bandwidth aside, DWDM's most compelling technical advantages can be summarized as follows:

- Transparency—Because DWDM is physical layer architecture, it can transparently support both TDM and data formats such as ATM, Gigabit Ethernet and Fiber Channel with open interfaces over a common physical layer.
- Scalability—DWDM can leverage the abundance of dark fiber in many metropolitan area and enterprise networks to quickly meet demand for capacity on point-to-point links and on spans of existing SONET/SDH rings.
- Dynamic provisioning—Fast, simple, and dynamic provisioning of network connections give providers the ability to provide high-bandwidth services in days rather than months.

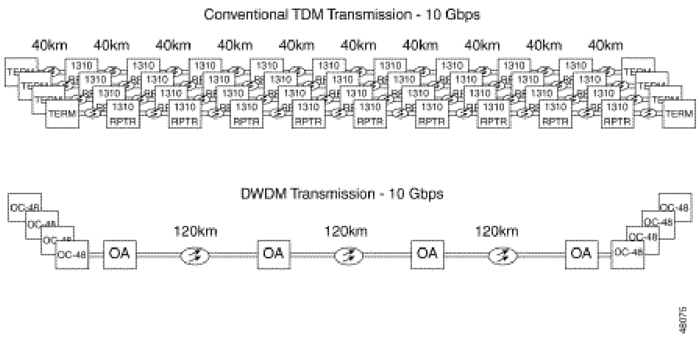

Figure 1-5: DWDM Eliminates Regenerators

A single optical amplifier can reamplify all the channels on a DWDM fiber without demultiplexing and processing them individually, with a cost approaching that of a single regenerator. The optical amplifier merely amplifies the signals; it does not reshape, retime or retransmit them as a regenerator does, so the signals may still need to be regenerated periodically. But depending on system design, signals can now be transmitted anywhere from 600 to thousands of kilometers without regeneration.

In addition to dramatically reducing the cost of regenerators, DWDM systems greatly simplify the expansion of network capacity. The only requirement is to install additional or higher bit-rate interfaces in the DWDM systems at either end of the fiber. In some cases it will only be necessary to increase the number of lambdas on the fiber by deploying existing interfaces, as shown in the upper half of Figure 1-6. The existing optical amplifiers amplify the new channel without additional regenerators. In the case of adding higher bit-rate interfaces, as shown in the lower half of Figure 1-6, fiber type can become a consideration.

Although amplifiers are of great benefit in long-haul transport, they are often unnecessary in metropolitan networks. Where distances between network elements are relatively short, signal strength and integrity can be adequate without amplification. But with MANs expanding in deeper into long-haul reaches, amplifiers will become useful.

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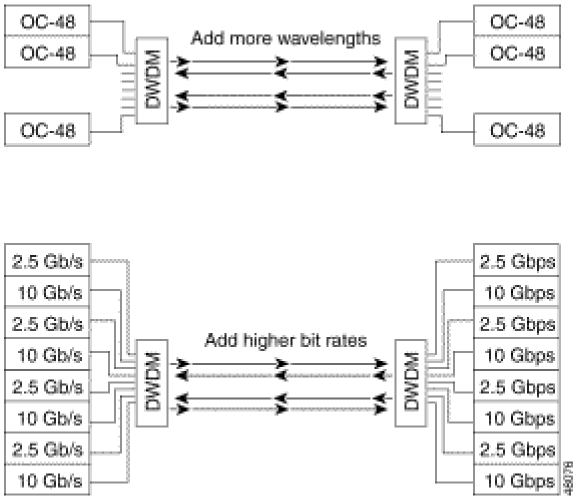

Figure 1-6: Upgrading with DWDM

7.1 Enhancing Performance and Reliability

Today's metropolitan and enterprise networks support many mission-critical applications that require high availability, such as billing and accounting on mainframes or client-server installations in data centers. Continuous backups or reliable decentralized data processing and storage are essential. These applications, along with disaster recovery and parallel processing, have high requirements for performance and reliability. As enterprises out source data services and inter-LAN connectivity, the burden of service falls on the service provider rather than on the enterprise.

With DWDM, the transport network is theoretically unconstrained by the speed of available electronics. There is no need for optical-electrical-optical (OEO) conversion when using optical amplifiers, rather than regenerators, on the physical link. Although not yet prevalent, direct optical interfaces to DWDM equipment can also eliminate the need for an OEO function.

Many components, such as the optical add/drop multiplexer (OADM), are passive and therefore continue to work, even if there is a power cut. In addition, these components tend to have a very high mean time between failures (MTBF). Protection schemes implemented on DWDM equipment and in the network designs are at least as robust as those built into SONET. All these factors contribute to better performance and lower maintenance in the optical network.

7.2 Additional Benefits

The shift in the makeup of traffic from voice to data has important implications for the design and operation of carrier networks. The introduction of cell-switching technologies such as ATM and Frame Relay demonstrates the limitations of the narrow-band, circuit-switched network design, but the limits of these technologies are being reached. Data is no longer an add-on to the voice-centric network, but is central. There are fundamentally different requirements of a data-centric network; two of these are the aggregation model and the open versus proprietary interfaces.

Aggregation in a voice-centric network consists of multiplexing numerous times onto transmission facilities and at many points in the network. Aggregation in a data-centric network, by contrast, tends to happen at the edge. With OC-48 (and higher) interfaces readily available on cell and packet switches, it becomes possible to eliminate costly SONET multiplexing and digital cross-connect equipment. OC-48 connections can interface directly to DWDM equipment.

VIII. CONCLUSIONS

Hence we conclude that one of the major issues in the networking industry today is tremendous demand for more and more bandwidth. Before the introduction of optical networks, the reduced availability of fibers became a big problem for the network providers. However, with the development of optical networks and the use of Dense Wavelength Division Multiplexing (DWDM) technology, a new and probably, a very crucial milestone is being reached in network evolution. The existing SONET/SDH network architecture is best suited for voice traffic rather than today’s high-speed data traffic. Finally, service providers and enterprises can respond more quickly to changing demands by allocating bandwidth on demand. The ability to provision services rapidly by providing wavelength on demand creates new revenue opportunities such as wavelength leasing (an alternative to leasing of physical links or bit rate-limited tunnels), disaster recovery, and optical VPNs. Some options for increasing carrier bandwidth are discussed. Protection schemes implemented on DWDM equipment and in the network designs are at least as robust as those built into SONET. All these factors contribute to better performance and lower maintenance in the optical network.

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