Dense Wavelength Division Multiplexing

ATG's Communications & Networking Technology Guide Series

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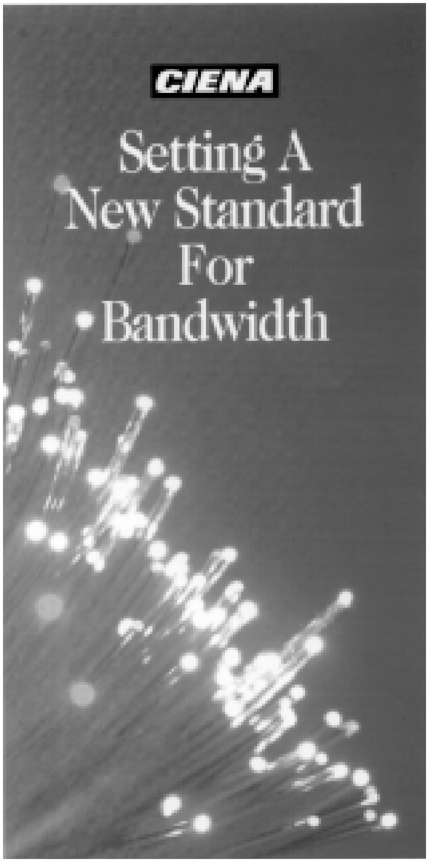
The Bandwidth Standard



CIENA Corporation develops, manufactures and markets high capacity fiber optic transmission systems for public networks. These systems unlock fiber bandwidth, improve network reliability, and significantly reduce the cost of providing new broadband services. CIENA's transparent optical systems deliver transmission capacities many times greater than any in service today. Development of such advanced, high capacity transmission and switching systems represent a challenge that can not be addressed solely by application of electronic time division multiplexing. Through the application of its advanced technology, CIENA is setting a new standard for bandwidth.

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About the Editor...

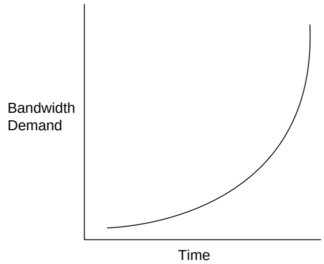
Gerald P. Ryan is the founder of Connections Telecommunications Inc., a Massachusetts-based company specializing in consulting, education and software tools which address Wide Area Network issues. Mr. Ryan has developed and taught numerous courses in network analysis and design for carriers, government agencies and private industry. Connections has provided consulting support in the areas of WAN network design, negotiation with carriers for contract pricing and services, technology acquisition, customized software development for network administration, billing and auditing of telecommunications expenses, project management, and RFP generation. Mr. Ryan is a member of the Networld+Interop program committee.

Introduction

Over the last decade, fiber optic cables have been installed by carriers as the backbone of their interoffice networks, becoming the mainstay of the telecommunications infrastructure. Using time division multiplexing (TDM) technology, carriers now routinely transmit information at 2.4 Gb/s on a single fiber, with some deploying equipment that quadruples that rate to 10 Gb/s. The revolution in high bandwidth applications and the explosive growth of the Internet, however, have created capacity demands that exceed traditional TDM limits. As a result, the once seemingly inexhaustible bandwidth promised by the deployment of optical fiber in the 1980s is being exhausted. To meet growing demands for bandwidth, a technology called Dense Wavelength Division Multiplexing (DWDM) has been developed that multiplies the capacity of a single fiber. DWDM systems being deployed today can increase a single fiber's capacity sixteen fold, to a throughput of 40 Gb/s! This cutting edge technology—when combined with network management systems and add-drop multiplexers—enables carriers to adopt optically-based transmission networks that will meet the next generation of bandwidth demand at a significantly lower cost than installing new fiber.

The Growing Demand

It is clear that as we approach the 21st century the remarkable revolution in information services has permeated our society. Communication, which in the past was confined to narrowband voice signals, now demands a high quality visual, audio, and data context. Every aspect of human interplay—from business, to entertainment, to government, to academia—increasingly depends on rapid and reliable communication networks. Indeed, the advent of the Internet alone is introducing millions of individuals to a new world of information and technology. The telecommunications industry, however, is struggling to keep pace with these changes. Early predictions that current fiber capacities would be adequate for our needs into the next century have proven wrong.



Bandwidth Demand Driven By…

…Growing Competition

During the past several years, a trend has developed throughout the world to encourage competition in the telecommunication sector through government deregulation and market-driven economic stimulation. Since competition was introduced into the US long-distance market in 1984, revenues and access lines have grown 40 percent, while investment in outside plant has increased 60 percent. The 1996 Telecommunication Reform Act is giving way to an even broader array of new operators, both in the long-distance and local-exchange sectors, which promise to drive down telecommunications costs and thereby create new demand for additional services and capacity. Moreover, while early competition among long distance carriers was based mainly on a strategy of price reduction, today's competitive advantage depends increasingly on maximizing the available capacity of network infrastructures and providing enhanced reliability.

…Network Survivability

Another significant cause of bandwidth demand is the carriers' need to guarantee fail-safe networks. As telecommunications has become more critical to businesses and individuals, service providers have been required to ensure that their networks are fault tolerant and impervious to outages. In many cases, telephone companies must include service level guarantees in business contracts, with severe financial penalties should outages occur.

To meet these requirements, carriers have broadened route diversity, either through ring configurations or 1:1 point-to-point networks in which back-up capacity is provided on alternate fibers. Achieving 100% reliability, however, requires that spare capacity be set aside and dedicated only to a backup function. This potentially doubles the bandwidth need of an already strained and overloaded system, since the "protective" path capacity must equal that of the revenue-generating "working path."

…New Applications

At the same time that carriers are enhancing network survivability, they must also accommodate growing customer demand for services such as video, high resolution graphics, and large volume data processing that require unprecedented amounts of bandwidth. Technologies such as Frame Relay and ATM are also adding to the need for capacity. Internet usage, which some analysts predict will grow by 700 percent annually in coming years, is threatening to overwhelm telephone access networks and further strain the nation's fiber backbone. The growth of cellular and PCS is also placing more demand on fiber networks, which serve as the backbone even for wireless communications.

Telecommunications Infrastructure Good But Overwhelmed

Since the early 1980s, the telecommunications infrastructure—built on a hierarchy of high performance central office switches and copper lines—has been migrating to massive computerization and deployment of fiber optic cables. The widespread use of fiber has been made possible, in part, by the industry's acceptance of SONET and SDH as the standard for signal generation.[1] Using SONET/SDH standards, telecommunication companies have gradually expanded their capacity by increasing data transmission rates, to the point that many carriers now routinely transport 2.4 Gb/s (STM–16/OC–48).

The bad news, however, is that the once seemingly inexhaustible capacity promised by ever increasing SONET rates is reaching its limit. In fact, bandwidth demand is already approaching the maximum capacity available in some networks. Primarily because of technical limitations and the physical properties of

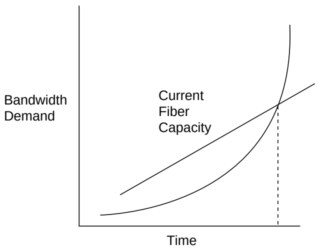
1 SONET is a North American standard promulgated by the American National Standards Institute (ANSI). There is an equivalent standard approved by the International Telecomunications Union (ITU) called Synchronous Digital Hierarchy (SDH). SONET and SDH refer to similar data transmission rates. Synchronous Transfer Mode (STM) is used to describe SDH rates, while the Optical Carrier (OC) designation applies to SONET–based systems. STM–16/OC–48 transmits 2.48 Gb/s, while STM–64/OC192 transmits almost 10 Gb/s.

embedded fiber, today there is a practical ceiling of 2.4 Gb/s on most fiber networks, although there are instances where STM–64/OC–192 is being deployed. Surprisingly, however, the TDM equipment installed today utilizes less than 1% of the intrinsic capacity of the fiber!

Achieving Bandwidth Capacity Goals

Confronted by the need for more capacity, carriers have three possible solutions:

- Install new fiber.
- Invest in new TDM technology to achieve faster bit rates.
- Deploy Dense Wavelength Division Multiplexing.



Installing New Fiber to Meet Capacity Needs

For years, carriers have expanded their networks by deploying new fiber and transmission equipment. For each new fiber deployed, the carrier could add capacity up to 2.4 Gb/s. Unfortunately, such deployment is frequently difficult and always costly. The average cost to deploy the additional fiber cable, excluding costs of associated support systems and electronics, has been estimated to be about $70,000 per mile, with costs escalating in densely populated areas. While this projection varies from place to place, installing new fiber can be a daunting prospect, particularly for carriers with tens of thousands of route miles. In many cases, the right-of-way of the cable route or the premises needed to house transmission equipment is owned by a third party, such as a railroad or even a competitor. Moreover, single-mode fiber is currently in short supply owing to production limitations, potentially adding to costs and delays. For these reasons, the comprehensive deployment of additional fiber is an impractical, if not impossible, solution for many carriers.

Higher Speed TDM — Deploying STM-64/OC-192 (10 Gb/s)

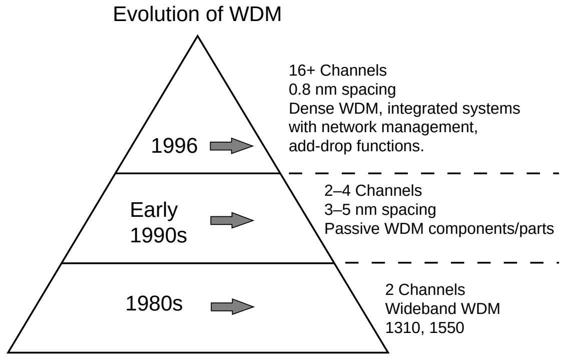
As indicated earlier, STM–64/OC–192 is becoming an option for carriers seeking higher capacity, but there are significant issues surrounding this solution that may restrict its applicability. The vast majority of the existing fiber plant is single-mode fiber (SMF) that has high dispersion in the 1550 nm window, making STM–64/OC–192 transmission difficult. In fact, dispersion has a 16 times greater effect with STM–64/OC–192 equipment than with STM–16/OC–48. As a result, effective STM–64/OC–192 transmission requires either some form of dispersion compensating fiber or entire new fiber builds using non-zero dispersion shifted fiber (NZDSF)—which costs some 50 percent more than SMF. The greater carrier transmission power associated with the higher bit rates also introduces nonlinear optical effects that cause degraded wave form quality.

The effects of Polarization Mode Dispersion (PMD)—which, like other forms of dispersion affects the distance a light pulse can travel without signal degradation—is of particular concern for STM-64/OC–192. This problem, barely noticed until recently, has become significant because as transmission speeds increase, dispersion problems grow exponentially thereby dramatically reducing the distance a signal can travel. PMD appears to limit the reliable reach of STM–64/OC–192 to about 70 kms on most embedded fiber. Although there is a vigorous and ongoing debate within the industry over the extent of PMD problems, some key issues are already known.

- PMD is particularly acute in the conventional single-mode fiber that comprises the vast majority of the existing fiber plant, as well as in aerial fiber.
- Unlike other forms of dispersion that are fairly predictable and easy to measure, PMD varies significantly from cable to cable. Moreover, PMD is affected by environmental conditions, making it difficult to determine ways to offset its effect on high bit rate systems.
- As a result, carriers must test nearly every span of fiber for its compatibility with STM–64/OC–192; in many cases, PMD will rule out its deployment altogether.

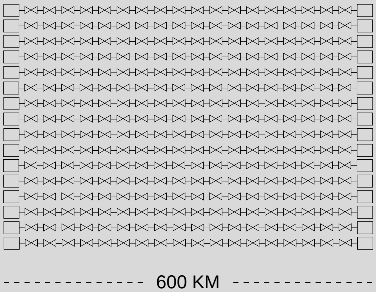
A Third Approach – DWDM

Dense Wavelength Division Multiplexing (DWDM) is a technology that allows multiple information streams to be transmitted simultaneously over a single fiber at data rates as high as the fiber plant will allow (e.g. 2.4 Gb/s). The DWDM approach multiplies the simple 2.4 Gb/s system by up to 16 times, giving an immense and immediate increase in capacity—using embedded fiber! A sixteen channel system (which is available today) supports 40 Gb/s in each direction over a fiber pair, while a 40 channel system under development will support 100 Gb/s, the equivalent of ten STM–64/OC–192 transmitters! The benefits of DWDM over the first two options—adding fiber plant or deploying STM–64/OC–192—for increasing capacity are clear.



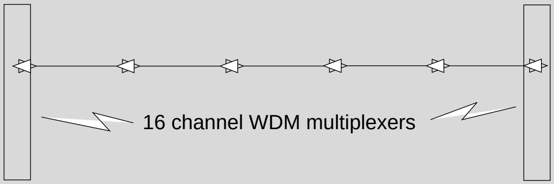
Dense Wavelength Division Multiplexing

DWDM technology utilizes a composite optical signal carrying multiple information streams, each transmitted on a distinct optical wavelength. Although wavelength division multiplexing has been a known technology for several years, its early application was restricted to providing two widely separated "wideband" wavelengths, or to manufacturing components that separated up to four channels. Only recently has the technology evolved to the point that parallel wavelengths can be densely packed and integrated into a transmission system, with multiple, simultaneous, extremely high frequency signals in the 192 to 200 terahertz (THz) range. By conforming to the ITU channel plan, such a system ensures interoperability with other equipment and allows service providers to be well positioned to deploy optical solutions throughout their networks. The 16 channel system in essence provides a virtual 16–fiber cable, with each frequency channel serving as a unique STM–16/OC–48 carrier.

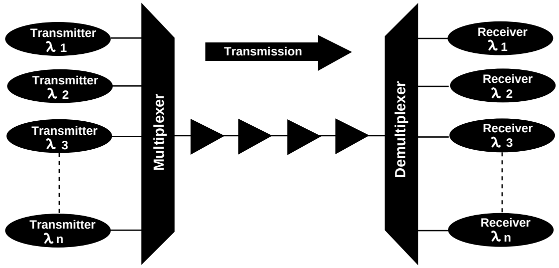


To transmit 40 Gb/s over 600 kms using a traditional system would require 16 separate fiber pairs with regenerators placed every 35 kms for a total of 272 regenerators.

A 16 channel DWDM system, on the other hand, uses a single fiber pair and 4 amplifiers positioned every 120 kms for a total of 600 kms.



The most common form of DWDM uses a fiber pair—one for transmission and one for reception. Systems do exist in which a single fiber is used for bi-directional traffic, but these configurations must sacrifice some fiber capacity by setting aside a guard band to prevent channel mixing; they also degrade amplifier performance. In addition, there is a greater risk that reflections occurring during maintenance or repair could damage the amplifiers. In any event, the availability of mature supporting technologies, like precise demultiplexers and Erbium Doped Fiber Amplifiers (EDFA), has enabled DWDM with eight, sixteen, or even higher channel counts to be commercially delivered.



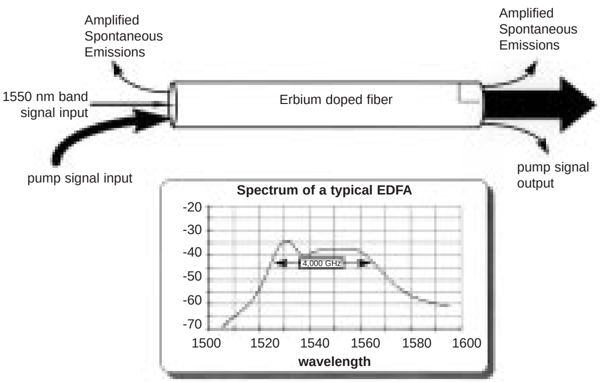
Demultiplexers

With signals as precise and as dense as those used in DWDM, there needed to be a way to provide accurate signal separation, or filtration, on the optical receiver. Such a solution also needed to be easy to implement and essentially maintenance free. Early filtering technology was either too imprecise for DWDM, too sensitive to temperature variations and polarization, too vulnerable to crosstalk from neighboring channels, or too costly. This restricted the evolution of DWDM. To meet the requirements for higher performance, a more robust filtering technology was developed that makes DWDM possible on a cost effective basis: the in–fiber Bragg grating.

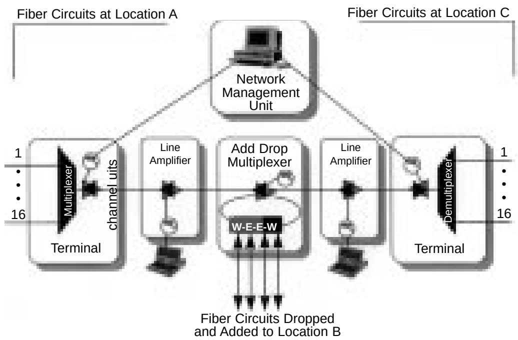
The new filter component, called a fiber grating, consists of a length of optical fiber wherein the refractive index of the core has been permanently modified in a periodic fashion, generally by exposure to an ultraviolet interference pattern. The result is a component which acts as a wavelength dependent reflector and is useful for precise wavelength separation. In other words, the fiber grating creates a highly selective, narrow bandwidth filter that functions somewhat like a mirror and provides significantly greater wavelength selectivity than any other optical technology. The filter wavelength can be controlled during fabrication through simple geometric considerations which enable reproducible accuracy. Because this is a passive device, fabricated into glass fiber, it is robust and durable.

Erbium Doped Fiber Amplifier

Optical Amplifier



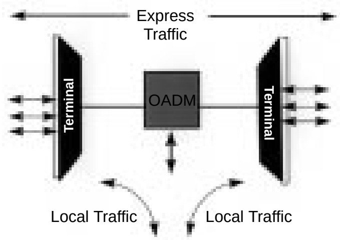
The advent of the Erbium Doped Fiber Amplifier (EDFA) enabled commercial development of DWDM systems by providing a way to amplify all the wavelengths at the same time. This optical amplification is done by incorporating Erbium ions into the core of a special fiber in a process known as doping. Optical pump lasers are then used to transfer high levels of energy to the special fiber, energizing the Eribum ions which then boost the optical signals that are passing through. Significantly, the atomic structure of Erbium provides amplification to the broad spectral range required for densely packed wavelengths operating in the 1550–nm region, optically boosting the DWDM signals. Instead of multiple electronic regenerators, which required that the optical signals be converted to electrical signals then back again to optical ones, the EDFA directly amplifies the optical signals. Hence the composite optical signals can travel up to 600 kms without regeneration and up to 120 kms between amplifiers in a commercially available, terrestrial, DWDM system.



Parlaying New Technologies into a DWDM System

The fiber Bragg grating and the EDFA represented significant technological breakthroughs in their own right, but the bandwidth potential associated with these innovations could only be realized by their incorporation into integrated DWDM transport systems for optical networks. Without such a development the fiber grating would retain component status similar to other passive WDM devices, while the power potential of EDFAs would remain underutilized. The ability to harness the potential of these technologies, however, is realizable today through commercially available, integrated, DWDM systems. Such a system is attained through the use of Optical Add–Drop Multiplexers (OADM) and sophisticated network management tools.

Add/Drop Configuration



Optical Add–Drop Multiplexers

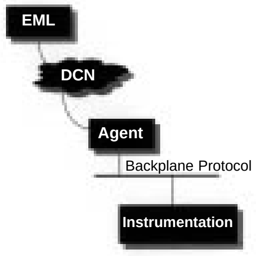
The OADM based on DWDM technology is moving the telecommunications industry significantly closer to the development of optical networks. The OADM can be placed between two end terminals along any route and be substituted for an optical amplifier. Commercially available OADMs allow carriers to drop and/or add up to four STM–16/OC–48 channels between DWDM terminals. The OADM has "express channels" that allow certain wavelengths to pass through the node uninterrupted, as well as broadcast capabilities that enable information on up to four channels to be dropped and simultaneously continue as "express channels." By deploying an OADM instead of an optical amplifier, service providers can gain flexibility to distribute revenue–generating traffic and reduce costs associated with deploying end terminals at low traffic areas along a route. The OADM is especially well-suited for meshed or branched network configurations, as well as for ring architectures used to enhance survivability. Such flexibility is less achievable with current STM64/OC–192 offerings.

Network Management

A critical yet often under appreciated part of any telecommunications network is the management system—whose reliability is especially vital in the complex and high capacity world of DWDM. Indeed, dependable and easily accessible network management services increasingly will become a distinguishing characteristic of high-performance, high-capacity systems. Today's leading DWDM systems include integrated, network management programs that are designed to work in conjunction with other operations support systems (OSSs) and are compliant with the standards the International Telecommunication Union (ITU) has established for Telecommunications Management Network (TMN). Current systems utilize an optical service channel that is independent of the working channels of the DWDM product to create a standards–based data communications network that allows service providers to remotely monitor and control system performance and use. This network manager communicates with each node in the system and also provides dual homing access and self–healing routing information in the event of a network disruption. By meeting ITU standards and utilizing a Q3 interface, the system ensures that end users retain high Operations, Administration, Maintenance, and Provisioning (OAM&P) service.

Network Management

Layered Architecture



- **Element Management Layer**
  - Standards based, GUI, Unix
  - Equipment & Service MO Views
- **DCN**
  - IP/Internet protocol based
  - Self healing service channel
- **Agent Layer**
  - Menu based craft interface
  - Protocol independent
- **Backplane**
  - Redundant NE M&C bus
- **Instrumentation**
  - Intelligent plug-in modules

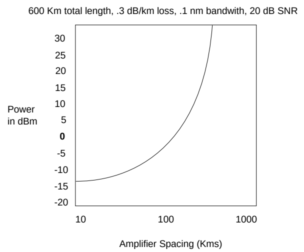
Measurements of Performance

There are several aspects that make the design of DWDM systems unique. A spectrum of DWDM channels may begin to accumulate tilt and ripple effects as the signals propagate along a chain of amplifiers. Furthermore, each amplifier introduces amplified spontaneous emissions (ASE) into the system, which cause a decrease in the signal to noise ratio, leading to signal degradation. Upon photodetection, some other features of optically amplified systems come into play. The Bit Error Rate (BER) is determined differently in an optically amplified system than in a conventional regenerated one. The probability of error in the latter is dominated by the amount of receiver noise. In a properly designed optically amplified system, the probability of error in the reception of a binary value of one is determined by the signal mixing with the ASE, while the probability of error in the reception of a binary value of zero is determined by the ASE noise value alone.

Optical SNR and Transmitted Power Requirements of DWDM Systems

Ultimately, the BER performance of a DWDM channel is determined by the optical SNR that is delivered to the photodetector. In a typical commercial system, an optical SNR of approximately 20 dB, measured in a 0.1 nm bandwidth, is required for an acceptably low BER of 10–15. This acceptable SNR is delivered through a relatively sophisticated analysis of signal strength per channel, amplifier distances, and the frequency spacing between channels.

For a specific SNR at the receiver, the amount of transmit power required in each channel is linearly proportional to the number of amplifiers as well as the noise and SNR of each amplifier, and is exponentially proportional to the loss between amplifiers. Because total transmit power is constrained by present laser technology and fiber nonlinearities, the workable key factor is amplifier spacing. This is illustrated in the accompanying graph by showing the relationship for a fiber plant with a loss of .3 dB/km, a receiver with a .1nm optical bandwidth, and optical amplifiers with a 5 dB noise figure. The system illustrated is expected to cover 600 kms and the optical SNR required at the receiver is 20 dB measured in the 0.1 nm bandwidth.



Fiber Non Linearities

In addition to ASE accumulation and dispersion, there are several types of fiber nonlinearities that can further limit the performance of any fiber optic transmission system—including those that use DWDM. These nonlinearities fall into two broad groups: scattering and refractive index phenomena.

Scattering Phenomena

One subtype of this phenomena is known as Stimulated Brillouin Scattering (SBS), which is caused by the interaction between the optical signal and acoustic waves in the fiber. The result is that power from the optical signal can be scattered back towards the transmitter. SBS is a narrowband process that affects each channel in a DWDM system individually, but which is even more pronounced in STM–64/OC–192 systems, due to the greater power levels required for their transmission.

A second form of scattering is known as Stimulated Raman Scattering (SRS), which is prompted by the interaction of the optical signal with silica molecules in the fiber. This interaction can lead to the transfer of power from shorter wavelength, higher photon energy channels, to longer wavelength, lower photon energy channels. Unlike SBS, SRS is a wideband phenomena that affects the entire optical spectrum that is being transmitted. SRS can actually cause a spectrum of equal amplitude channels to tilt as it moves through the fiber. Moreover, its impact worsens as power is increased and as the total width of the DWDM spectrum widens. One way to combat this phenomena is to use moderate channel powers as well as a densely packed channel plan that minimizes the overall width of the spectrum.

Refractive Index Phenomena

This group of nonlinearities includes self-phase modulation (SPM), cross-phase modulation (CPM), and four-wave mixing (FWM). These are caused because the index of refraction, and hence the speed of propagation in a fiber, is dependent on the intensity of light—a dependency that can have particularly significant effects in long–haul applications. SPM, which refers to the modulation that a light pulse has on its own phase, acts on each DWDM channel independently. The phenomena causes the signal's spectrum to widen and can lead to crosstalk or an unexpected dispersion penalty. By contrast, CPM is due to intensity fluctuations in another channel and is an effect that is unique to DWDM systems. Finally, four-wave mixing refers to the nonlinear combination of two or more optical signals in such a way that they produce new optical frequencies. Although four-wave mixing is generally not a concern in conventional single-mode fiber, it can be particularly troublesome in the dispersion shifted fiber that is used to propagate STM64/OC192. As a result, carriers that opt for STM–64/OC–192 equipment to relieve today's congestion may unintentionally be limiting their ability to grow their capacity through future deployment of DWDM.

All three types of refractive index phenomena can be controlled either through careful choice of channel power or increases in channel spacing.[2]

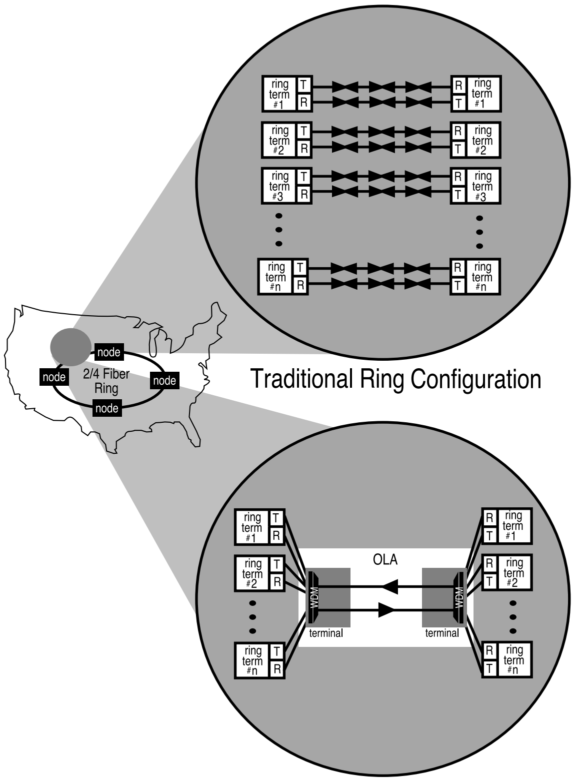
2 See—*Transmission of Many WDM Channels Through a Cascade of EDFAs in Long distance Links and Ring Networks*—Alan Willner and Syang Myau Hwang IEEE 0733–872/95 Journal of Lightwave Technology

Applications for DWDM

As occurs with many new technologies, the potential ways in which DWDM can be used are only beginning to be explored. Already, however, the technology has proven to be particularly well suited for several vital applications.

- DWDM is ready made for long-distance telecommunications operators that use either point–to–point or ring topologies. The sudden availability of 16 new transmission channels where there used to be one dramatically improves an operator's ability to expand capacity and simultaneously set aside backup bandwidth without installing new fiber.
- This large amount of capacity is critical to the development of self-healing rings, which characterize today's most sophisticated telecom networks. By deploying DWDM terminals, an operator can construct a 100% protected, 40 Gb/s ring, with 16 separate communication signals using only two fibers.
- Operators that are building or expanding their networks will also find DWDM to be an economical way to incrementally increase capacity, rapidly provision new equipment for needed expansion, and future–proof their infrastructure against unforeseen bandwidth demands.
- Network wholesalers can take advantage of DWDM to lease capacity, rather than entire fibers, either to existing operators or to new market entrants. DWDM will be especially attractive to companies that have low fiber count cables that were installed primarily for internal operations but that could now be used to generate telecommunications revenue.

SONET RINGS

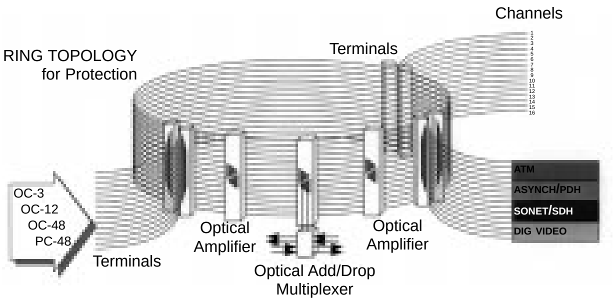


- The transparency of DWDM systems to various bit rates and protocols will also allow carriers to tailor and segregate services to various customers along the same transmission routes. DWDM allows a carrier to provide STM–4/OC–12 service to one customer and STM–16/OC–48 service to another all on a shared ring!
- In regions with a fast growing industrial base DWDM is also one way to utilize the existing thin fiber plant to quickly meet burgeoning demand.

The Future of DWDM—Building Block of the Photonic Network

DWDM is already established as the preferred architecture for relieving the bandwidth crunch many carriers face. Several US carriers have settled on DWDM at STM–16/OC–48 rates as their technology of choice for gaining more capacity. With 16 channel DWDM now being deployed throughout the carrier infrastructure, and with a 40 channel system coming, DWDM will continue to be an essential element of future interoffice fiber systems. Indeed, deployment of DWDM is a critical first step toward the establishment of photonic networks in the access, interoffice, and interexchange segments of today's telecommunication infrastructure.

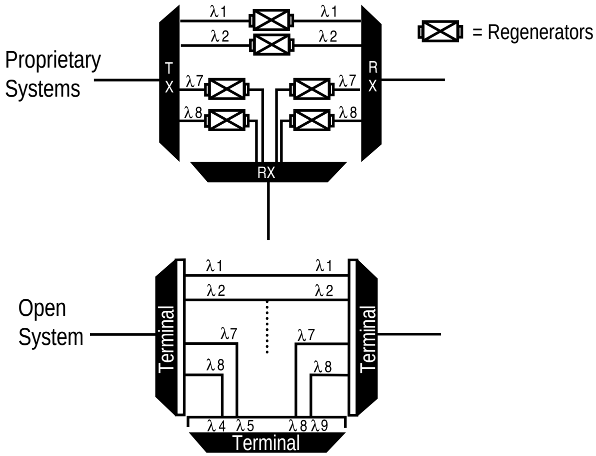
The Photonic Network



Given the rapidly changing and unpredictable nature of the telecommunications industry, it is imperative that today's DWDM systems have the ability to adapt to future technological deployments and network configurations. DWDM systems with an open architecture provide such adaptability and prepare service providers to take full advantage of the emerging photonic network.

- For example, DWDM systems with open interfaces give operators the flexibility to provide SONET/SDH, asynchronous/PDH, ATM, Frame Relay, and other protocols over the same fiber. Open systems also eliminate the need for additional high-performance optical transmitters to be added to a network when the need arises to interface with specific protocols. Rather, open systems allow service providers to quickly adapt new technologies to the optical network through the use of "off-the-shelf," relatively inexpensive, and readily available transmitters.
- In contrast to DWDM equipment based on proprietary specifications, systems with open interfaces provide operators greater freedom to provision services and reduce long-term costs. Proprietary based systems, in which SONET/SDH equipment is integrated into the optical multiplexer/demultiplexer unit, are adequate for straight point–to–point configurations. Nevertheless, they require additional and costly transmission equipment when deployed in meshed networks.

Open vs. Proprietary System



- Finally, DWDM systems that comply with the ITU channel plan will reassure carriers that they are deploying technology with recognized industry standards and the flexibility needed to grow their optical networks into long distance, local exchange, and eventually access networks.

In the space of two years, DWDM has become recognized as an industry standard that will find acceptance in any carrier environment. Deployment of DWDM will allow new services to come on-line more quickly, help contain costs so that prospective customers can more easily afford new services, and readily overcome technological barriers associated with more traditional solutions. Its acceptance will drive the expansion of the optical layer throughout the telecommunications network and allow service operators to exploit the enormous bandwidth capacity that is inherent in optical fiber but that has gone largely untapped—until now.

ANNEX: Practical Considerations of DWDM Deployment

Based on bit rate alone, DWDM has a fourfold advantage even over the latest—albeit nascent—TDM option, STM–64/OC–192. To fairly compare the two technologies, however, we need to review and outline what would be an ideal technological solution for expanding network capacity. This has to be done in a broad sense, recognizing that there are instances in which TDM may offer a better solution than DWDM. Analyzing the alternative attributes and benefits of each approach would require a comparison of several key issues:

1. Compatibility with Fiber Plant.
   The majority of the legacy fiber plant cannot support high bit rate TDM. Earlier vintage fiber has some attributes that lead to significant dispersion and would, therefore, be incompatible with high bit rate TDM. Recently produced fiber—NZDSF, for example—is flexible enough for the latest TDM equipment, but it is expensive and may limit the ability of carriers to migrate to the greater bandwidth available through DWDM at STM–16/OC–48 rates.
2. Transparency and Interoperability.
   The chosen solution must provide interoperability between all vendors' transmission equipment, both existing and new. It must be vendor independent and conform to international standards such as the proposed ITU channel spacing and be based on the Open Systems Interconnection (OSI) model. Furthermore, it must be capable of supporting mixed protocols and signal formats. Some commercially available DWDM systems provide such transparency and can be used with any SONET/SDH bit rates, as well as with asynchronous/PDH protocols.
3. Migration and Provisioning Strategy.
   The best solution must also offer the ability to expand. It must be capable of supporting differing bit rates and have channel upgrade capability. It has to be a long-term solution and not just a short-term fix. TDM systems already are reaching their technological barriers and STM–64/OC–192, although rich in capacity, may represent a practical limit that could only be superseded by DWDM.
4. Network Management. A properly engineered solution should also support a comprehensive network element management system. The solu-

tion must meet international standards, interface with the carrier's existing operating system, and provide direct connection for all of the network elements for performance monitoring, fault identification and isolation, and remedial action. Sophisticated and reliable network management programs will become increasingly important to deal with the increased complexity and expanded capacity that will be unleashed through migration to optical networks.

5. Technical Constraints. The systems deployed must be able to resolve some of the outstanding technical issues present in current lightwave transmission systems. For example, signal dispersion compensation, filtering and channel cross talk, nonlinear four-wave mixing, and physical equipment density are some of the more common problems. Ideally, an optimized system level architecture that provides a coherent and unified approach should be chosen over one that involves the acquisition and deployment of components on a piecemeal and uncoordinated basis.

CASE STUDY: How CIENA Corporation Teamed With Sprint to Break the Fiber Bandwidth Barrier

"We knew we had the best kind of business problem," said Douglas McKinley, Director of Network Planning for Sprint, the global communications company. "In early 1995, we forecast unprecedented growth in the Sprint network. We had huge customers all coming to us asking Sprint to carry their long distance traffic. Along with all of our other customers, they wanted everything - voice, video, data - and they wanted it fast. How were we going to give them the capacity they needed?"

For Sprint, the challenge was to provide customers with desperately needed bandwidth in a timely and reliable manner. The solution also needed to be cost effective. And, one of the most important requirements was that the expanded network capacity had to take advantage of the facilities Sprint already had in place.

Sprint had built the United States' only nationwide all-digital, fiber optic network that served more than 15 million businesses and residential customers. A leader in the industry, Sprint was the country's first major provider of long distance, local, and wireless services. In addition, Sprint is the world's largest carrier of Internet traffic.

The explosive growth of Internet-related applications coupled with the surge in all types of network traffic made 1995 a watershed year for the company. In addition, the passage of the Telecommunications Act of 1996 unleashed a torrent of activity in the telecommunications marketplace with many of the new long distance companies leasing facilities from Sprint.

Ideally, the bandwidth capacity expansion solution Sprint sought would also complement the carrier's complete commitment to a SONET fiber network. In 1993, Sprint committed to a Synchronous Optical Network (SONET) technology, and the company is now the only long-distance carrier with a four-fiber, bi-directional, line-switching ring topology (four-fiber, BLSR) installed from coast-to-coast and from border-to-border. The four-fiber BLSR allows customers on Sprint's SONET network to survive network outages and fiber cuts in milliseconds. The company anticipates that the majority of its customers will be on the SONET network by the end of 1997.

"We started looking for the solution at the conceptual stage," recalled Bill Szeto, Manager of Engineering for Sprint. "We needed the best companies in the business to focus their resources on this capacity problem so we called in a few well-known manufacturers along with CIENA Corporation, a relatively new company in Maryland which we knew was developing high-capacity fiber optic transmission systems.

"Teaming with CIENA was just the right thing to do. Starting with just the concept, the solution took less than a year to complete. It was unheard of in the industry, considering the complexity of the problem to have this happen in such a short time frame. One of the reasons it was able to happen this way is because CIENA is knowledgeable. And, working right along with Sprint's technical people, there was synergy to work efficiently, closely, and effectively."

The solution that CIENA developed, called the CIENA MultiWave™ 1600 system, far exceeded the parameters required. The 16 window, dense wavelength division multiplexing (DWDM) technology allows Sprint to increase the capacity of its fiber network by a factor of 16 without installing more fiber optic cable. In essence, it gives Sprint 16 virtual fibers where it once had one. The system meets the need for more bandwidth and provides Sprint with more capability in its installed plant.

In short, the CIENA MultiWave 1600 builds on existing fiber optic technology and increases its efficiency dramatically. By expanding the transmission capability of fiber already installed, Sprint can meet and exceed its customers' current requirements, as well as the anticipated delivery of new interactive multimedia services.

Fiber optics transmit data as pulses of light moving at 124,000 miles per second. More than 2.5 billion bits of information per second can be carried over long-distance fiber. To keep the pulses from fading, fiber-optic cables use amplifiers and regenerators to recharge the power of the light approximately every 60 miles.

"Traditionally, we could carry about 32 thousand transmissions in a fiber at one time," explains Szeto. "With CIENA's MultiWave 1600 system we can carry 16 times this. All at once, we essentially expanded from our 32 thousand capacity to a capability of carrying 512 thousand calls at the same time.

"Efficiency is also a factor," he continued. "When you used fiber without DWDM for high-bandwidth applications, you had to use more fiber. If we can use fewer fibers, we can increase capacity for new services using our existing fiber base. And, that can translate into cost savings for customers." Economies of scale are also apparent to Sprint with the technology offering 16 times the capacity at a fraction of the cost, according to Szeto.

The CIENA MultiWave product is a high-capacity, optical transmission system which enables aggregate transmission capacities up to 40 Gigabits per second (40 Gb/s) over existing fiber facilities. Sixteen discrete channels can transmit over one fiber. Each channel is bit-rate transparent from 150 Mb/s to 2.4 Gb/s and operates with existing SONET/SDH/Asynchronous fiber optic terminals.

This available capacity per fiber allows Sprint's network designers to fine tune each network span according to the customer's or Sprint's own internal requirements.

The system also incorporates optical line amplifiers to extend the transmission range. Designed specifically for DWDM, the amplifier is capable of amplifying the system's entire 16 channel, 40 Gb/s capacity. Two optical service channel modems enable access to local network management data and all the elements of the MultiWave system.

In addition, CIENA's MultiWave system for Sprint is equipped with an integrated network management system that includes an optical service channel with a 2.048 Mb/s capacity, that supports the Data Communications Network (DCN). The DCN communicates system management information throughout the Sprint network and enables vital remote access to performance monitoring and control, as well as multiple simultaneous craft interface access. Self-healing information routing in the event of network disruption and dual homing access is also included.

Embedded throughout the system is instrumentation that observes, measures, and records the status and operation of every module. Distributed system intelligence analyzes, processes, and stores the data gleaned from the instrumentation. On an element-by-element basis, performance and fault information data can be accessed and manipulated by Sprint network managers.

Sprint is deploying CIENA's MultiWave 1600 on selected routes throughout its network. In fact, DWDM is pervasive throughout the Sprint network, especially in high traffic areas.

"CIENA was given a business problem and we gave them only a short time to solve it. By working closely with us, CIENA has helped Sprint maintain its technology leadership in the telecommunications industry," McKinley commented.

Marty Kaplan, senior vice president and chief technology officer for Sprint, added, "The CIENA solution protects our existing investment and allows us to incrementally expand the transmission capacity of our network as we deliver new broadband services to our customers,"

And, demand for more capacity to deliver those services isn't going away soon. "Nineteen months ago analysts were saying they thought four - and eight - channel WDM would be enough for the foreseeable future," noted Steve Chaddick, senior vice president of products and technologies at CIENA. "The foreseeable future turned out to be about three months."

"The CIENA solution protects our existing investment and allows us to incrementally expand the transmission capacity of our network..." Marty Kaplan, Senior Vice President and Chief Technology Officer, Sprint

Glossary

Add-Drop (OADM)—Optionally allows up to four optical wavelengths to be added or dropped at any line amplifier location.

Add/Drop Multiplexer (ADM)—A multiplexer capable of extracting or inserting lower-rate signals from a higher-rate multiplexed signal without completely demultiplexing the signal.

American National Standards Institute (ANSI)—The coordinating body for voluntary standards groups within the United States. ANSI is a member of the International Organization for Standardization (ISO).

Backbone—(1) The part of a network used as the primary path for transporting traffic between network segments. (2) A high-speed line or series of connections that forms a major pathway within a network.

Bandwidth—(1) Measure of the information capacity of a transmission channel. (2) The difference between the highest and lowest frequencies of a band that can be passed by a transmission medium without undue distortion, such as the AM band - 535 to 1705 kilohertz. (3) Information carrying capacity of a communication channel. Analog bandwidth is the range of signal frequencies that can be transmitted by a communication channel or network. (4) A term used to indicate the amount of transmission or processing capacity possessed by a system or a specific location in a system (usually a network system).

Bandwidth On Demand Interoperability Group (BONDING)—Makers of inverse muxes.

Bit—(1) The smallest unit of information in the binary system of notation. (2) One binary digit; a pulse of data. (2) A binary digit, either a zero or one. The smallest element of a computer program. In the U.S., eight bits make up one byte.

Bit Error Rate (BER)—Percentage of bits in a transmittal received in error. (2) The number of coding violations detected in a unit of time, usually one second.

Bits Per Second (bps)—(1) The number of bits passing a point every second. The transmission rate for digital information. (2) A measurement of how fast data are moved from one place to another. (Example: a 28.8 modem can move 28,800 bps.)

Broadband—A data-transmission scheme in which multiple signals share the bandwidth of a medium. This allows the transmission of voice, data, and video signals over a single medium. Cable television uses broadband techniques to deliver dozens of channels over one cable.

Capacity—The information carrying ability of a telecommunications facility. What the “facility” is determines the measurement. You might measure a line’s capacity in bits per second. You might measure a switch’s capacity in the maximum number of calls it can switch in one hour, or the maximum number of calls it can keep in conversation simultaneously.

Carrier—A company which provides communications circuits. Carriers are split into “private” and “common.” A private carrier can refuse you service. A “common” carrier cannot. Most of the carriers in our industry—your local phone company, AT&T, MCI US, Sprint, etc.—are common carriers. Common carriers are regulated. Private carriers are not.

Channel—(1) A communication path. Multiple channels can be multiplexed over a single cable in certain environments. The term is also used to describe the specific path between large computers and attached peripherals. (2) An electrical or photonic, in the case of fiber optic-based transmission systems, communications path between two or more points of termination. (3) The smallest subdivision of a circuit that provides a type of communication service; usually a path with only one direction.

CIENA MultiWave™ 1600—A dense wavelength division multiplexing (DWDM) system that is capable of transmitting up to sixteen (16) discrete optical channels over one fiber pair. Each channel is bit-rate transparent from 150 Mb/s to 2.4 Gb/s and operates with existing SONET/SDH/Asynch fiber optic terminals. This system incorporates optical line amplifiers to extend the transmission range, and it offers integrated network management facilities.

Deregulation—The removal of regulatory authority to control certain activities of telephone companies. An attempt by federal authorities to make the telephone industry more competitive. Deregulation is meant to benefit the consumer.

Erbium Doped Fiber Amplifier (EDFA)—Erbium Doped Fiber Amplifiers have become the dominant method for signal amplification in long-haul lightwave transmission systems. EDFAs differ from the normal method of regenerative or electro-optic repeaters in that light does not have to be converted to an electrical signal, amplified, and then converted back to light. Optical amplifiers contain a length of fiber that is doped with erbium doped (a rare earth substance) that provides the gain medium, an energy source or "pump" from a laser source at the correct frequency, and a coupler to couple the pump laser to the doped fiber. Both the signal to be amplified and the pump energy are coupled into the doped fiber section of the transmission system. The pump laser puts the erbium-doped fiber into an excited state where it is able to provide optical gain through emission stimulated by a passing signal photon. One of the most important features, after the fact that EDFAs are amazingly simple, is that they are not frequency dependent, and therefore allow bandwidth upgrades (within limits) without replacing the entire transmission systems. Undersea transmission systems, such as Americas 1, TAT-12/13, and TCP-5 use EDFA technology.

Fiber In the Loop (FITL)—Optical technology from CO to customer premises.

Fiber Optical Bragg Grating—An optical fiber grating is an optical fiber component consisting of a length of optical fiber wherein the refractive index of the core has been permanently modified in a periodic fashion, generally by exposure to an optical interference pattern as generated by an ultraviolet laser.

Fiber Optic Cable—A transmission medium that uses glass or plastic fibers, rather than copper wire, to transport data or voice signals. The signal is imposed on the fiber via pulses (modulation) of light from a laser or a light-emitting diode (LED). Because of its high bandwidth and lack of susceptibility to interference, fiber-optic cable is used in long-haul or noisy applications.

Fiber Optics—A method for the transmission of information (sound, pictures, data). Light is modulated and transmitted over high purity, hair-thin fibers of glass. The bandwidth capacity of fiber optic cable is much greater than that of conventional cable or copper wire.

Fiber Plant—Arial or buried fiber optic cable that established connectivity between fiber optic transmission equipment locations.

Frequency—(1) Measures the number of electromagnetic waves that pass a given point in a given time period. It is equal to the speed of light, divided by wavelengths and is expressed in cycles per second or hertz. (2) The number of cycles of periodic activity that occur in a discrete amount of time.

Gigabits Per Second (Gb/s)—Billion bits per second. A measure of transmission speed.

Infrastructure—The basic facilities, services, and installations needed for the functioning of a community or society such as transportation and communications systems.

Interexchange Carrier (IXC) or Interexchange Common Carrier—(1) Any individual, partnership, association, joint-stock company, trust, governmental entity, or corporation engaged for hire in interstate or foreign communication by wire or radio, between two or more exchanges. (2) A long-distance telephone company offering circuit-switched, leased-line or packet-switched service or some combination.

Interoperability Technology Association for Information Processing (INTAP)—The technical organization which has the official charter to develop Japanese OSI profiles and conformance tests.

ITU—International Telecommunications Union

Local Exchange Company (LEC)—A telephone company that provides customer access to the worldwide public switched network through one of its central offices.

Megabit (Mb/s)—One million bits.

Megabits Per Second (Mb/s)—A digital transmission speed of millions of bits per second.

Multi-conductor copper cable—Provides transmission facilities for VF and digital services up to 1.5MB/s. Upper bit rate growth possible through new technology such as ADSL (Adaptive Digital Subscriber Loop).

Multimode—Used to describe optical fiber that allows more than one mode of light signal transmission. Multimode fibers are generally used for short-distance links.

Multimode Fiber—Optical fiber supporting propagation of multiple modes of light.

Multiplexer (MUX)—Equipment that enables several data streams to be sent over a single physical line. It is also a function by which one connection from an (ISO) layer is used to support more than one connection to the next higher layer. (2) A device for combining several channels to be carried by one line or fiber.

Multiplexing—In data transmission, a function that permits two or more data sources to share a common transmission medium such that each data source has its own channel.

Network Element (NE)—Any device which is part of a communications transmission path and serves one or more of the section, line, or path terminating functions.

Network Management System (NMS)—A system responsible for managing at least part of a network. NMSs communicate with agents to help keep track of network statistics, resources, and performance.

OC-192—Optical carrier Level 192. Sonet bit rate of 10 Gb/s.

OC-48—Optical carrier Level 48. Sonet bit rate of 2.4 Gb/s.

Optical Carrier (OC-x)—Fundamental unit used in SONET (Synchronous Optical NETwork) hierarchy. OC indicates an optical signal and x represents increments of 51.84 Mbps. OC-1, -3, and -12 equal optical rates of 51, 155, and 622 Mbps.

Optical Carrier 1 (OC-1)—ITU-ISS physical standard for optical fiber used in transmission systems operating at 51.84 Mb/s.

Optical Carrier 3 (OC-3)—Optical Carrier level 3, SONET rate of 155.52 Mb/s, matches STS-3.

OSI—Open Systems Interconnection. The only internationally accepted framework of standards for communication between different systems made by different vendors. OSI was developed by the International Standards Organization (ISO). ISO's major goal is to create an open systems networking environment where any vendor's computer system, connected to any network, can freely share data with any other computer system on that network or a linked network. Most of the dominant communications protocols used today have a structure based on the OSI model. The OSI model organizes the communications process into seven different categories and places the categories in a layered sequence based on their relation to other user. Layers seven through four deal with end to end communications between the message source and the message destination, while layers three through one deal with network access.

Pleisiochronous Digital Hierarchy (PDH)—Asynchronous multiplexing scheme from T1 to T3 and higher; contrast with SDH.

Provider—A company that provides an interface between the teleservices platform and an installed telephone device, such as a telephone line or a fax machine.

Public Network—A network operated by common carriers or telecommunications administrations for the provision of circuit-switched, packet-switched and leased-line circuits to the public.

Public Switched Network—The combined transmission facilities of the world's telephone companies and administrations, including all those circuits available to subscribers on an unrestricted basis.

Regenerator—Device that restores a degraded digital signal for continued transmission; also called a repeater.

Regional Bell Operating Company (RBOC)—(1) One of six telephone companies created after AT&T divestiture. (2) The acronym for the local telephone companies created in 1984 as part of the breakup of AT&T. The six RBOCs are Ameritech, Bell Atlantic, Bell South, NYNEX, Southwestern Bell, and U.S. West.

Repeater—(1) A device that regenerates and propagates electrical signals between two network segments. (2) Device that restores a degraded digital signal for continued transmission; also called a regenerator.

Ring—Connection of network elements in a circular logical topology.

Ring Topology—Topology in which the network consists of a series of repeaters, add-drop multiplexers, or terminals. Ring networks are relatively immune to interruption and fiber cuts, because of the multiple transmission paths that are implied in the ring.

Signaling—(1) The process of sending a transmission signal over a physical medium for purposes of communication. (2) Method of communication between network components to provide control management and performance monitoring.

Single Mode—Used to describe optical fiber that allows only one mode of light signal transmission.

Single-mode Fiber—Also called monomode. Single-mode fiber has a narrow core that allows light to enter only at a single angle. Such fiber has higher bandwidth than multimode fiber, but requires a light source with a narrow spectral width (for example, a LASER).

Survivability—A property of a system, subsystem, equipment, process, or procedure that provides a defined degree of assurance that the device or system will continue to work during and after a natural or man-made disturbance.

Switch—A device which filters, forwards, and directs frames or circuits based on destination address.

Synchronous Digital Hierarchy (SDH)—ITU-TSS international standard for transmission over optical fiber.

Synchronous Optical Network (SONET)—
(1) A set of standards for transmitting digital information over optical networks. “Synchronous” indicates that all pieces of the SONET signal can be tied to a single clock. (2) A CCITT standard for synchronous transmission up to multigigabit speeds. (3) A standard for fiber optics.

Synchronous Transport Signal 1 (STS-1)—
(1) SONET standard for transmission over OC-1 optical fiber at 51.84 Mb/s. (2) A SONET frame including overhead and payload capacity. The basic SONET frame is the STS-1. STS-1s can be multiplexed or concatenated with no additional overhead.

Time Division Multiplexing (TDM)—Technique where information from multiple channels may be allocated bandwidth on a single wire based on time slot assignment.

TMN—Telecommunication Management Network. A concept where all OMCs (Operation and Maintenance Centers) are linked together to form a network. A centralization occurs to facilitate control, monitoring, and management of all devices in the communications network.

Transport Layer—OSI layer that is responsible for reliable end-to-end data transfer between end systems.

Unidirectional—Operating in only one direction.

Wavelength—The length of one complete wave of an alternating or vibrating phenomenon, generally measured from crest to crest or from trough to trough of successive waves.

Wavelength Division Multiplexing (WDM)—two or more colors of light on one fiber.

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"The significant problems we face cannot be solved by the same level of thinking that created them."

Albert Einstein

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