A SUPPLEMENT TO BUSINESS COMMUNICATIONS REVIEW

THE EVOLUTION OF DWDM

PERSPECTIVE AND OVERVIEW

The world of telecommunications networking is changing, and rapidly. Where once we had kilobits, we now demand megabits. Where we now have megabits, we want gigabits. Where we have gigabits, we will soon be using terabits.

People—businesses, institutions, organizations—are finding ways to use bandwidth as never before. While this has been triggered in large part by the rise of the Internet, it also stems from a host of other factors and, more important, from a critical idea: We are becoming an information society. As we evolve from our industrial past to an information-based future, the economics of our businesses and institutions are also shifting on their axes and the demand for more bandwidth is becoming a key driver in our society.

There is no turning back; nobody using personal computers wants to return to electric typewriters, just as those who use email won't return to writing letters full time. This is a natural phenomenon, which can't be stayed by a few doubters, such as modern-day King Canutes.

King Canute was an ancient Danish monarch who one day commanded his subjects to accompany him to the sea. There, from his throne planted in the sand, he commanded the ocean tides to cease. Needless to say, it didn't take long for Canute's throne to become swamped with salt water, despite the lofty position he held within his realm.

The expansion of our networks to be more data centric through the use of dense wavelength division multiplexing (DWDM) and other optical networking processes is as certain as the ebb and flow of the ocean tides, despite the efforts of those who would try to limit or shoehorn their scope. We here at CIENA would not have it any other way.

The purpose of this supplement is to provide our thoughts as to where the evolution of this DWDM network—and the broader data network that it is becoming integrated with it—are headed. We believe the effects will be profound—and that networking will never again be quite the same.

In "DWDM in Emerging Data-Centric Carrier Networks," Charles Chi explains how voice-oriented networks as we know them are changing, and how DWDM is being used to assure a smooth transition to a data-oriented world.

In the next article, "Migration of SONET/SDH to DWDM and Other Protocols," CIENA's Joe Berthold and Stephen B. Alexander detail how SONET/SDH functions will be replaced as data-centric networking becomes a reality.

In the final article, "The Coming Ubiquitous DWDM Network," drawing on CIENA's experience at the forefront of this wondrous new technology, I offer some thoughts about how a seamless DWDM network will connect throughout the communications network environment.

DWDM is at the vanguard of a fundamental shift in network capabilities and economics. Those of us at CIENA hope that this supplement will help position you and your company to take advantage of the changes that are about to unfold.

C. David Chaffee
Corporate Editor
CIENA Corp.

DWDM IN EMERGING, DATA-CENTRIC CARRIER NETWORKS

by Charles Chi

By most accounts, the growth of data traffic is outstripping that of voice by at least ten to one. While voice traffic is growing at a compound annual rate of 13 percent, the growth in data traffic is estimated at between 7 and 20 percent—*per month*. The only question for carriers is when data traffic volumes will surpass those of voice (see Figure 1).

This fundamental shift in the character of the traffic has profound implications for how carrier networks are designed, built and operated. Historically, carrier-network architectures have evolved along with the growth of the predominant traffic type—circuit-switched voice. Data was accommodated as well as possible on the voice-centric narrowband network.

The limitations of narrowband, circuit-switched technologies for transporting data have been clear for some time, as evidenced by the deployment of cell- and packet-switching technologies such as ATM and frame relay. We have reached the point where data services can no longer be handled by optimizing the old, circuit-switched infrastructure. New network architectures need to be considered, architectures that are crafted from the outset to manage the dynamics of data traffic. Not doing so risks creating network bottlenecks and missing customer demand in an increasingly competitive market.

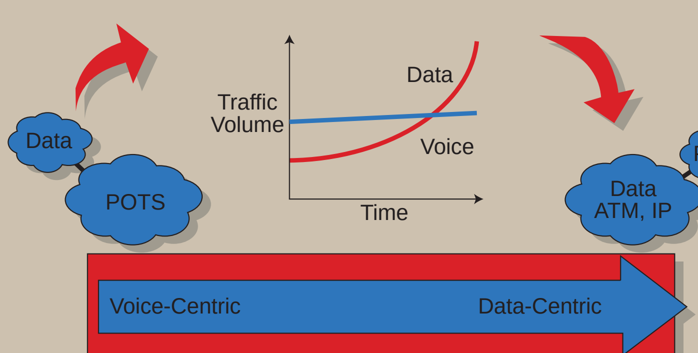

FIGURE 1 DATA TRAFFIC POISED TO OVERTAKE VOICE

Many carriers recognize these shifts in the market, and while there still are some technical debates about which switching technology to use, there is clear consensus that a transition is needed to a data-centric network architecture—i.e., one that uses packets, cells or both as the fundamental switching technology. Data traffic is no longer just an "add-on" service; indeed, in the emerging data-centric model, circuit-switched voice traffic becomes a service transported over the packet/cell infrastructure.

...Bandwidth Is a Necessity

The data-centric network operates in a fundamentally different way from the voice-centric network. The voice-centric network consists of switching millions of DS0 circuits. Between switching points, each circuit is multiplexed numerous times for aggregation onto transmission facilities. Aggregation occurs at many points in the network: from access, to within the central office (CO), and then to the inter-CO. A significant cost of a carrier's network goes to the equipment that performs this aggregation. This includes 0/1/3 cross-connects and SONET multiplexers.

Instead of switching millions of physical circuits, the data-centric network switches virtual circuits or even just packets. Aggregation of physical circuits tends to happen at the edge of the carrier network. The first ATM or IP switch immediately converts the physical circuit to a virtual circuit or to a stream of packets (see Figure 2).

The speed of the transmission facilities between switches directly affects the performance of these networks, which is why many IP and ATM switches have or will have OC-48c/STM16 interfaces this year. The OC-12c/STM4 interfaces are readily available today on these switches. Furthermore, ATM and IP switch vendors are introducing K1/K2 byte protection switching in addition to their network-wide routing currently available.

One of the major consequences of this evolution affects the network elements that aggregate physical circuits. OC-48c interfaces on a switch may eliminate the need for an entire layer of aggregation. There is little benefit to connecting a switch's OC-48c output to an OC-48 SONET multiplexer, because the port speeds have already reached the interface speed of the optical layer. Hence, ATM and IP switches can connect directly to the optical network provided by DWDM, which in turn can yield tremendous cost savings (see Figure 3).

DWDM solves the bandwidth bottleneck brought about by the growth in data traffic and is a key technology for carriers and others building data-centric networks. The number of OC-48 channels made possible by DWDM is ideally suited to broadband IP and ATM switches. Sixteen, 40 and even 96 channels per fiber pair make OC-48 more readily available than OC-3 was just a year ago.

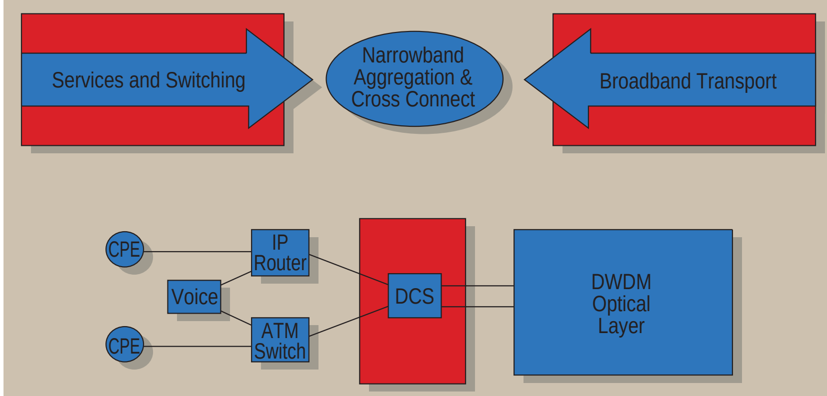

FIGURE 2 AGGREGATION AT THE EDGE

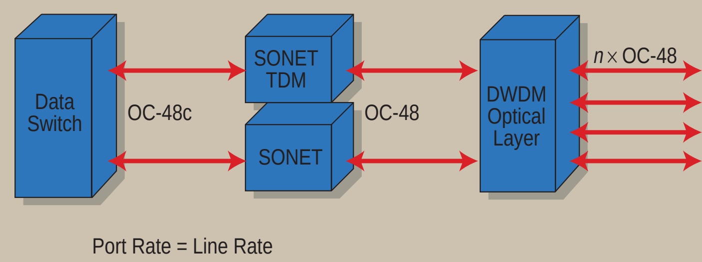

FIGURE 3 CONNECTING ATM & IP DIRECTLY TO THE OPTICAL NETWORK

...Open Systems Are a Must

A consideration for carriers implementing DWDM is open interfaces. DWDM network elements that support open interfaces allow SONET multiplexers, IP and ATM switches to be directly connected. In a closed-interface system, optics with specific wavelengths are used to interface between the SONET multiplexer and the DWDM network element. Without the intervening SONET multiplexer, it is not possible to connect an IP or ATM switch directly to DWDM, and closed systems require the SONET multiplexer to be from the same vendor as the DWDM equipment. In comparison, open systems can be lower in overall costs while providing greater flexibility.

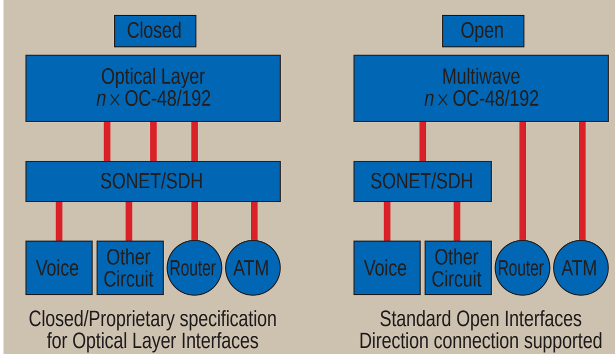

FIGURE 4 THE KEY—OPEN SYSTEMS

...Proven Solutions in Real Networks

DWDM will play a key role in carrier networks both today and in the future. DWDM is a proven solution for addressing the bandwidth bottleneck—CIENA MultiWave® DWDM systems are deployed in over 1 million channel kilometers in the United States, Asia and Europe. With open interfaces and the highest channel count in production, CIENA MultiWave DWDM systems will be instrumental in the emergence of the data-centric carrier network.

Charles Chi is manager, technical marketing at CIENA Corp.

MIGRATION OF SONET/SDH TO DWDM, OTHER PROTOCOLS

by Joe Berthold and Stephen B. Alexander

Fiber optic networks began carrying traffic some 20 years ago at the now humble bandwidth of 45 Mbps. At the time, it was recognized that optical fiber could soon carry significantly more capacity, but the engineering, particularly for laser stability, was at a primitive stage.

From the fiber optic base, the much-heralded evolution began to synchronous optical networking (SONET)/ synchronous digital hierarchy (SDH). SONET/SDH has provided an interface standard that promotes interoperability, protection mechanisms, network management and time-multiplexing hierarchy.

Today's network architectures deploy SONET/SDH as the transport system, sometimes in collaboration with DWDM. A number of services are carried over SONET transport systems, such as voice services, frame relay, ATM-based services and the Internet (see Figure 1).

...Toward More Robust Networking

A major concern related to SONET/SDH equipment in today's networks is that these networks were designed to manage traffic in the basic unit of a telephone call, 64 kbps, which is becoming almost an infinitesimally small unit when future traffic pattern rates are considered.

Data services already often run over T1 (1.544-Mbps) or T3 (44.736-Mbps) circuits, and even that level of bandwidth is turning out to be insufficient. A growing number of users already require SONET OC-3 (155 Mbps) and OC-12 (622 Mbps) channels. When carriers look to their options for provisioning such high-bandwidth services, they find that the equipment at their disposal is more complicated and expensive than they need, since it was designed to manipulate much more fine-grained traffic than currently is required.

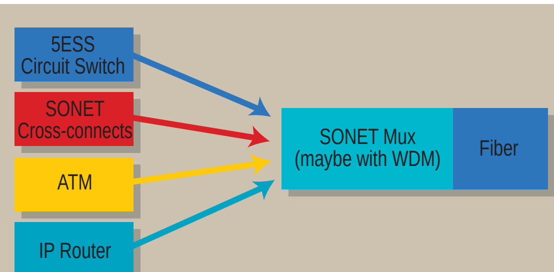

FIGURE 1 SONET TRANSPORT SYSTEM

Data networking equipment such as ATM, IP switches and IP routers can handle data traffic much more efficiently than can telephone voice switches. And with data traffic growing, transport networks will increasingly rely on data switches to manage bandwidth and aggregate traffic, while the transport network provides low-cost and reliable connections between the switches.

As data equipment evolves into this new central role, port speeds and total traffic throughput are increasing. Output ports soon will be available that run at the same speed as fiber-optic transmission systems—e.g., OC-48 (2.5 Gbps). The switches also will perform all the multiplexing necessary for transmission, thus eliminating the need for further levels of SONET multiplexing. SONET will continue to be the premier interface standard for wide-area transmission, but the equipment that embodies SONET is broadening to include data networking and DWDM.

Network operators who believe that future traffic growth will be dominated by data now see the opportunity offered by DWDM—it can lower their costs and simplify their networks. DWDM allows them to remove an entire class of equipment in their emerging, high-capacity, data-backbone networks. SONET multiplexers are no longer needed because time-division multiplexers are no longer needed. The last stage of data aggregation is done by cell and packet switches, and the bandwidth of optical fibers is then most efficiently
utilized by combining a large number of wavelengths, with each carrying a high-speed data channel.

It is easy to understand why this change has not occurred yet—and why it will take time to play out. The vast majority of data equipment in backbone networks still has lower-speed interfaces, 45 Mbps or 155 Mbps. DWDM will fill a backbone data need soon, and then move further toward the edges of the network. Also, as wavelength counts increase and manufacturing costs decrease, DWDM will become more economic in regional and access networks, even with channel speeds of 155 Mbps and 622 Mbps.

...The Changing Role of SONET/SDH

No one knows better than the network operator that networks are progressive, ongoing entities. One of the key advantages to DWDM is how easily it can be overlaid on existing networks, thus dramatically increasing capacity of the original network. While the current generation of SONET networking equipment, including terminal multiplexers, add/drop multiplexers and cross-connect switches, will continue to serve the needs of low-bandwidth, circuit-oriented traffic, SONET will no longer be the only choice for optical network transport equipment.

DWDM networking equipment will provide a new set of network elements, including DWDM terminals, DWDM add/drop multiplexers and optical channel cross-connect switches. DWDM networking equipment will fill two roles: economical transport of high-bandwidth SONET channels, which are the outputs of SONET equipment, and carrying the whole new class of data networking equipment that will form the basis of most of the traffic growth in the future (see Figure 2).

SONET will continue to be the interface standard of choice; without standard transport rates and formats, interoperability is impossible. Low-cost SONET interface components, in the form of the SONET 1300-nanometer (nm) short-reach interface, provide the most economical way to interconnect high-bandwidth channels to DWDM networking equipment, be they from SONET terminals or data equipment. CIENA Corporation already is offering this interface with its MultiWave® products.

DWDM equipment will build on the SONET standards, implementing mechanisms for channel identification and monitoring to make DWDM networks manageable. Signal regeneration will be integrated into DWDM terminals to assure scalability, and thus enable complex metropolitan- and national-scale networks to be assembled. Protection mechanisms will be introduced, enabling data services that need to have a high degree of survivability to obtain it from the DWDM layer without the added expense of SONET rings. At the same time, the DWDM layer will continue to support SONET rings.

DWDM networking equipment will also support the TMN management protocols required in large-carrier/ISP-type networks, as well as SNMP for managing enterprise and smaller ISP networks. Figure 3 shows SONET's new role as one of several protocols connecting to DWDM, which in turn transmits multiple signals through the fiber. We believe this represents a realistic view of how networks are evolving.

...Dense Wavelength Division Multiplexing: A Complete Network Architecture

DWDM began as a way to alleviate telecom traffic congestion in the long-distance marketplace. But it has become clear that the emerging multiwave optical layer will be used throughout the telecom network for

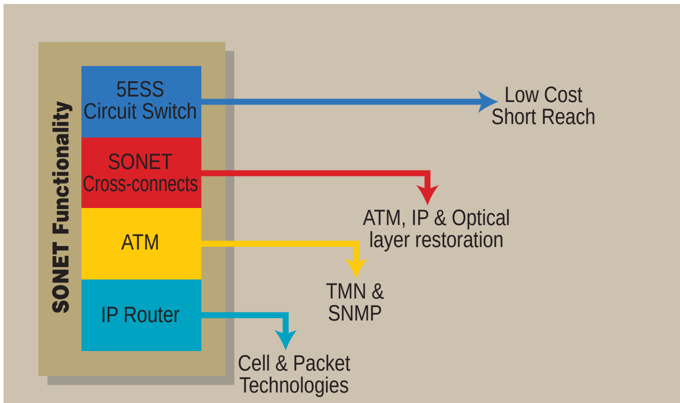

FIGURE 2 SOURCES OF NETWORK TRAFFIC

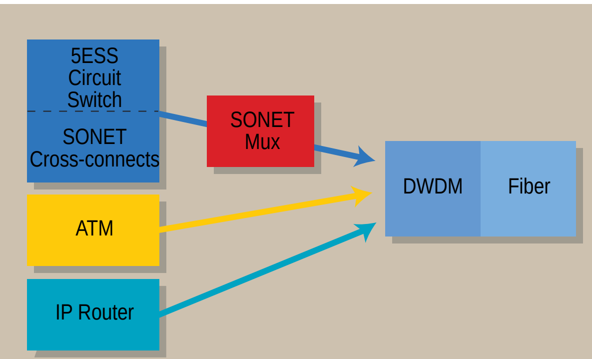

FIGURE 3 SONET AND OTHER PROTOCOLS CONNECT TO DWDM

DWDM networking will allow high-bandwidth channels to be delivered across complex networks in a simple, manageable and cost-effective way. This simplification of some of the key components of wide-area networking will provide network operators with the tools they need to offer more economical, high-bandwidth services, which, in turn, will lead to an even faster escalation in traffic.

CIENA, for example, has several DWDM products, including the MultiWave Sentry™ 1600 and MultiWave Sentry™ 4000 , which are geared to the long-distance market; the MultiWave® Firefly for short-haul applications; and, in development, the MultiWave Metro™ for metropolitan ring-type applications. (See pp. 6–8 in the supplement for a further discussion of how these products are defining DWDM networks.)

This is the philosophy behind the emerging multiwave optical layer: To deploy a clear and seamless DWDM network in a manner that interconnects with and allows existing networks to continue to function. DWDM will enable network operators to "future-proof" their networks to the bandwidth jolts and spikes that will continue to mark our Information Age.

Joe Berthold is vice president network architecture at CIENA Corp., and Steve Alexander

THE COMING UBIQUITOUS DWDM NETWORK

by C. David Chaffee

DWDM is a networking industry and technology in motion.

From an industry of little value only five years ago, revenues reached $1.57 billion last year and are expected to soar to $5.5 billion by 2000—just two years from now—according to the respected marketing house of ryan, hankin, kent.

From a technology that was delivering only two channels a few years ago, CIENA Corp. can now send 40 channels along an optical fiber, with the capability to expand to 96 channels.

What lessons has CIENA learned as it has become a prime innovator in the DWDM marketplace? And where is this marketplace going?

The initial DWDM market was the long-haul or interexchange carriers, who have the inter-city pipes with the greatest amount of traffic. These same routes were the first to substitute optical fiber cable for copper cable more than a decade ago.

The interexchange market provided a solid liftoff for the DWDM industry. The major U.S. interexchange carriers are using it in their networks, as are many of the international carriers. Most of the remaining IXCs and international carriers that haven't yet deployed DWDM are looking at it as their pipes increasingly become fiber constrained.

CIENA's first product, introduced in April 1996, was the MultiWave® 1600, the first DWDM system in the world to furnish 16 channels over one fiber. From the beginning, the primary emphasis was on solving fiber-constraint problems caused by new broadband services such as the Internet, and survivable SONET ring architectures, which call for up to 50 percent of a ring to be reserved for return traffic flow triggered by outages.

Yet shortly after DWDM began going into real systems, it became clear that it had unique networking characteristics that enabled it to move beyond being a fiber enabler; DWDM is destined to play a central role in the emerging optical network.

It also became evident that DWDM can be easily and seamlessly overlaid with existing networks, which dramatically expands a network's capacity. The tremendous growth in data suggests an overlay network that can meet this demand and also provide for growth.

From the initial product launch, CIENA has placed its emphasis on open-system network architectures, which interact with a variety of different equipment types and vendors.

An enabling technology for DWDM has been the marketplace development of the erbium-doped fiber amplifier (EDFA), which has the capability to boost signals photonically. The result is that the need for costly regenerators is decreased substantially. With MultiWave 1600, signals could be sent distances of 600 kilometers without SONET regenerators. These EDFAs replace the 16 costly SONET regenerators that would be necessary if operators were not to use DWDM.

...Sentry Introduces Important Changes as DWDM Systems Gain Sophistication

The integration of DWDM with other networking equipment is increasingly important as DWDM becomes more widespread in carrier networks. Rather than just interacting with SONET or SDH equipment, CIENA engineers began developing systems that could use short-reach interfaces to mix SONET, ATM and Fast IP onto a common optical network.

This was through a refinement of the MultiWave 1600 known as the MultiWave Sentry™. While it also offered 16-channels, MultiWave Sentry provided some important enhancements.

For example, MultiWave Sentry gave carriers the ability to send signals up to 800 kilometers without the need for signal regeneration through a SONET multiplexer. This was in part due to the wiser deployment of span management, which includes 25-dB amps as well as the more traditional 30-dB amps. CIENA now has a design where SONET multiplexers are no longer required in a network design.

CIENA also provided more flexibility along the route by incorporating optical add/drop multiplexers, which allowed operators to add or drop signals along a DWDM line. Here, again, CIENA was in the role of delivering an industry first.

As part of the MultiWave 1600 system, CIENA introduced the WaveWatcher® Network Management System. It includes the network element manager—the WaveWatcher EMS—which uses a separate out-of-band optical service channel to communicate with the network manager system and provides a single view of multiple CIENA systems through graphical user interfaces and supportive operating system interfaces.

A critical point regarding WaveWatcher is that it has been designed to adhere to evolving open-system standards for network management software and operates on a UNIX platform. The WaveWatcher Network Management System offers fault, performance, security and configuration management of optical-networking systems.

CIENA also recently introduced the MultiWave Sentry™ 4000, the industry's first 40-channel DWDM system in commercial production. The product provides 50-GHz channel spacings, also an industry first, and will allow the system to expand to 96 channels on a channel-by-channel basis.

The growth of network traffic did not confine itself to the long-haul market. Not long after DWDM was introduced, it became clear that there were some economic benefits to bringing it into the local exchange.

...Huge Customer Demand Signifies Migration to Short-Haul Market

In fact, a huge customer demand for low-cost, short-haul, bandwidth-enhancing products led to development of CIENA's short-haul DWDM products, says Jesús León, CIENA's vice president of product development.

"The message we got from customers made it absolutely clear that we needed to make a product to satisfy short-haul needs," León says. This knowledge came from extensive visits León and other CIENA personnel made to customers during late 1996 and early 1997.

CIENA entered the market for short-haul DWDM systems with the announcement of two leading-edge products at the NFOEC '97 show. These include the MultiWave® Firefly and MultiWave Metro™.

The MultiWave Firefly's two key features are that it allows carriers to transmit 24 channels, up from the 16 channels that had earlier been available, and that it costs 50 to 60 percent of what the long-distance products have been priced at, according to León.

Having spent a portion of his career in the European telecommunications market, León also sees a need for a short-reach, short-haul product to serve that marketplace. "The combination of my experience in Europe and the message we got from customers in the United States made it absolutely clear that we needed to make a product for the short-haul," he says.

It has become clear that there are economic benefits to bringing DWDM to the local exchange

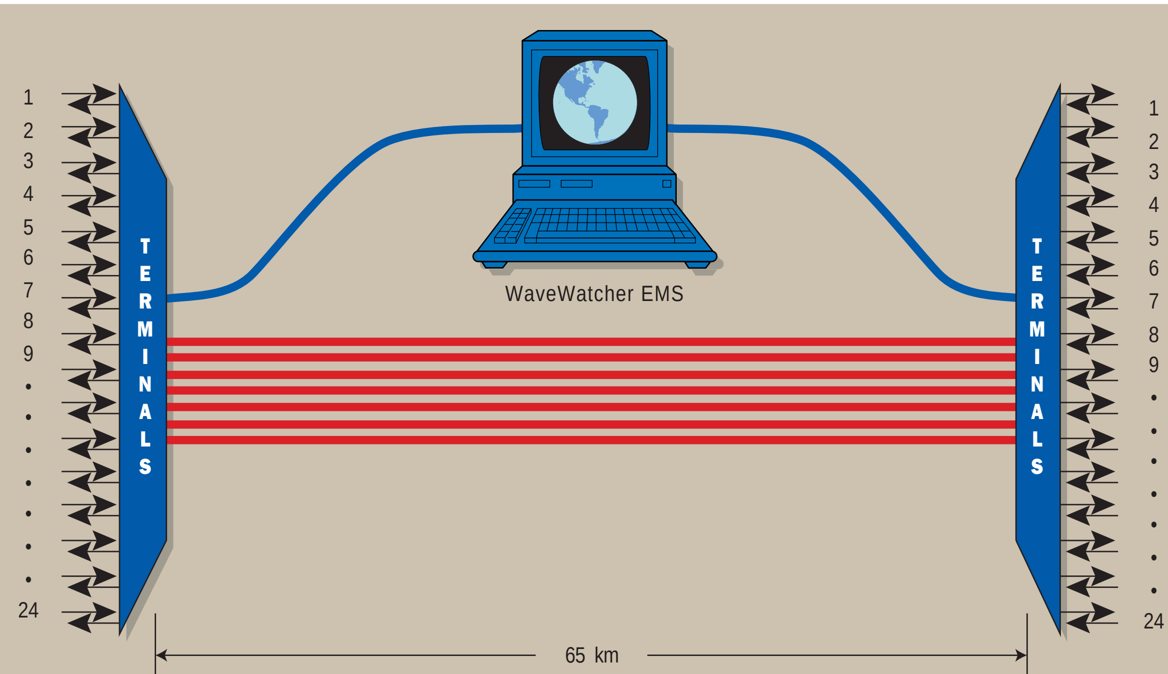

FIGURE 1 CIENA'S MULTIWAVE® FIREFLY

"Ciena's DWDM technology, developed for long-distance carriers, makes sense for short-haul operators."

"The problem they have—and it is the same problem we have seen in the long-haul market—is the huge growth fueled primarily by the Internet, but also by other data applications," he adds. "It seems like there is an insatiable demand for bandwidth out there."

...Customer Demand for MultiWave Firefly Has Been Phenomenal

"The customer demand for MultiWave Firefly has been phenomenal," says León. "It is one of those pleasant surprises, where you believe you have a good product but you don't know that for sure until the purchase orders start rolling in."

León estimates that the European market is approximately one to two years behind the U.S. market, in part because the pace of the Internet explosion elsewhere lags that of the U.S., but also because some PTTs have installed a lot of optical fiber cable. "With some European carriers, there is a significant demand for bandwidth, but with others the bandwidth requirement is not as great as it is in the United States," he pointed out.

MultiWave Firefly can offer 60 Gbps of bandwidth, and provides transport of signals up to 65 kilometers—without the need for amplifiers. Like CIENA's MultiWave Sentry product, MultiWave Firefly enables carriers to mix SONET/SDH, ATM and Fast IP traffic on a common optical network.

CIENA is also developing MultiWave Metro™, a ring-based metropolitan access network system using DWDM techniques to introduce as many as 16 different wavelengths around the ring. The target application is short spans, which have high aggregate bandwidth capacity with multiple applications, interfaces and data rates.

...Changing the Economics of Short-Haul Bandwidth

"With the introduction of DWDM products designed for short-distance applications, CIENA has effectively changed the economics of bandwidth in the short-haul market," says Dr. Patrick Nettles, CIENA's president and CEO.

"Previously, Regional Bell Operating Companies and other local exchange carriers faced with capacity constraints had few alternatives to expand bandwidth. MultiWave Firefly and MultiWave Metro bring the scalability and cost efficiencies of DWDM—greater bandwidth without additional fiber—to an entirely new base of customers," Nettles says. "Firefly and Metro represent an entirely new class of DWDM products, which are optimized both from a performance and cost perspective to meet
the bandwidth demands faced by the short-haul provider."

Another advantage of these short-haul products is that they simply and efficiently interconnect with CIENA's long-distance products. "All you need is a jumper wire between Sentry and Firefly and they will fully interconnect," León says.

John Ryan, a principal at ryan, hankin, kent, and coauthor of a recent report on DWDM, observes, "Local exchange carriers increasingly are faced with problems associated with fiber exhaust. CIENA has taken the DWDM technology it developed to allow long-distance carriers to rapidly deploy incremental bandwidth and optimized it so that it makes sense for short-haul operators."

Like CIENA's interexchange carrier product line, the MultiWave Firefly network manager is open systems–based. It provides flexible, standards-based network management to support TL1, Telecommunication Management Network (TMN) and Simple Network Management Protocol (SNMP).

MultiWave Metro can simultaneously aggregate multiple traffic types, including SONET/SDH (at both the SONET OC-12 and OC-48 and SDH STM-4 and STM-16 rates), ATM and fast IP in a ring environment, providing protection switching and able to add or drop traffic at various locations within the ring.

While MultiWave Metro does not compete with SONET, it has advantages over SONET. "The difference is that instead of carrying one ring of OC-48 as SONET may do, we may be able to do eight, 10, 12 or 16 rings, depending on the configuration," León says. The MultiWave Metro product also can carry different data rates—for example, it can drop OC-3s and OC-12s. "It is obvious that we should install MultiWave Metro when it comes to that or digging up the streets to install more fiber," León says.

Comparing WDM to time-division multiplexing, León notes, "There is a point where it makes sense to install more wavelengths. Below that, there is a point where it makes sense to install a higher TDM rate. For example, if you had a DS3 system, it would be much less expensive to go from DS3 to OC-3 than it would be to implement MultiWave Metro. But, if you go from OC-3 or OC-12 to OC-48 to OC-192, it is much less expensive to do it with Metro than it is to do it with the SONET solution."

The commingling of DWDM in the interexchange network and the local exchange network is leading to a seamless deployment of DWDM throughout the telecom network. This makes sense as Internet traffic balloons and enhanced services pervade the network.

C. David Chaffee is corporate editor at CIENA Corp.