ASSESSMENT OF PHOTONIC SWITCHES AS FUTURE REPLACEMENT FOR ELECTRONIC CROSS-CONNECT SWITCHES

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ABSTRACT

This paper presents the future of optical networking via photonic switches as a potential replacement for the existing electronic cross-connects. Although optical amplifiers are now mainstream and wave division multiplexing (WDM) systems are a commercial reality, the industry's long-term vision is one of the all-optical network. This will require optical switching equipment such as all-optical or "photonic" cross-connect switches that will provide packet switching at an optical layer. Currently, as voice calls or data traffic are routed throughout Range and commercial networks, the information can travel through many fiber-optic segments which are linked together using electronic cross-connects. However, this electronic portion of the network is the bottleneck that is preventing the ideal network from achieving optimal speeds. Information is converted from light into an electronic signal, routed to the next circuit pathway, then converted back into light as it travels to the next network destination. In an all-optical network, the electronics are removed from the equation, eliminating the need to convert the signals and thereby significantly improving network performance and throughput. Removing the electronics improves network reliability and restoration speeds in the event of an outage, provides greater flexibility in network provisioning, and provides a smooth transition when migrating to future optical transmission technologies. Despite the fact that photonic switching remains uncommercialized, it now seems apparent that the core switches in both the public networks and DoD Range networks of the early 21st century will probably carry ATM cells over a photonic switching fabric.

KEY WORDS

Photonic Switches, Cross-Connect Switches, Wave Division Multiplexing (WDM), Dense WDM (DWDM)

INTRODUCTION

In the research and development world, optical networking products have been around for more than a decade but have had little impact on telecommunications and data communications for several reasons. These products were expensive, sometimes unreliable, and it was unclear at the time that anyone needed the high bandwidths and switch capacities that optical networking had to offer. Today, issues such as the Range customer's ever-increasing bandwidth requirements, and the pressure that video and various other data traffic are expected to place on Range networks and wide area networks (WANs), is clearly proving that bandwidth requirements will continue to increase exponentially throughout the foreseeable future. It is not just the telemetry streams and advanced networking applications that are threatening to clog up the network. It is the heavy flow of digital traffic from such equipment as telephones, fax machines, PCs and local area networks (LANs) (email, Internet, and mission data to the desktop) that is an issue as well.

Fiber-optic networks began carrying traffic approximately 20 years ago. There was a well published evolution to synchronous optical network/synchronous digital hierarchy (SONET/SDH), which has provided a strong interface standard that promotes interoperability, protection mechanisms, network management, and time multiplexing hierarchy. A number of services are carried over SONET transport systems, including voice, frame relay and other data services, asynchronous transfer mode (ATM)-based services, and the Internet.

A major problem with the equipment in today's networks is that it was designed to manage traffic in the basic unit of a telephone call-64 kilobits per second (Kbps)-while future traffic growth will be mainly in cell- and packet-based services. Data networking equipment such as ATM or internet protocol (IP) switches and routers can handle data traffic much more efficiently than do telephone voice switches. About one-half of the traffic in the network today is data, but the majority is carried on low-speed channels in voice switches or SONET multiplexers.

In the laboratory, work continues on the concept of switching not just wavelengths of light but the individual packets of data transmitted over fiber networks, all of which are now processed with relatively slow electronic switches. The use of these electronic switches for fiber-optic data communications networks significantly limits the total processing capacity or speed of a network. An optical fiber is capable of carrying extremely high volumes of data-10 Gigabits per second (Gbps) and more. Currently, however, because of electronic switching limitations, the most popular high volume LAN protocol is fiber distributed data interface (FDDI), which operates at only 100 Megabits per second (Mbps). Even the fastest electronic switches are currently capable of processing only about 622 Mbps through each port. Meanwhile, improvements to optical transmission equipment will continue to increase the capacity of optical fibers. Since a network cannot effectively carry any more information than can be processed through its switches, the use of electronic switches reduces the capacity of a fiber-optic network from multi-gigabits per second to no more than 622 Mbps. The use of electronic switches in high-speed, high- volume fiber-optic networks is comparable to building a ten-lane superhighway, interspersed with a series of one-lane tunnels.

WAVE DIVISION MULTIPLEXING (WDM)

Wave Division Multiplexing (WDM) or Dense WDM (DWDM) is a process in which different streams of data are carried at different wavelengths across a single strand of optical fiber. This is in contrast with conventional fiber-optic systems in which just one stream of data is carried over a narrow bandwidth window.

Five years ago networks that incorporated DWDM were to be found in U.S. and European government-industry research consortia that were showcasing new technologies. This heavy-handed engineering term describes networking equipment that has, in the interim, rescued long-distance carriers such as the telecommunications provider Sprint from a bandwidth drought. The DWDM systems work in concert with optical amplifiers that can boost the strength of many wavelengths at once without having to convert the wave back into an electrical signal.

With this technology, the capacity of in-the-ground fiber can be expanded by simply adding wavelengths. For Sprint, deploying the multiplexers costs roughly 40 percent of the $77,000-per-mile expense of adding new fiber. The company uses DWDM on 90 percent of its 30,000 miles of fiber networks.

In many respects, the further implementation of DWDM in the network simply verifies that network operators believe DWDM can help them get more out of an optical fiber than other techniques. Since optical fiber can potentially transmit trillions of bits of information per second, it makes sense to center the network around a transport technology that enables operators to more effectively and efficiently use that potential. The DWDM is increasingly employed when the traffic exceeds the limits of what is economical to transport with time-division multiplexing.

All of these efforts, however, are temporarily avoiding the inevitable: the complete replacement of electronic switches and cross-connects with all-optical technology.

PHOTONIC SWITCHING TECHNOLOGIES

Today's digital cross-connects require that the multi-gigabit light waves that are channeled along fiber networks be converted to lower-rate electronic signals. Optical switching elements, expected in 1999, will be incorporated into the next generation of DWDM products. They will allow any wavelength in a fiber to be diverted onto or off a network on command, unlike current multiplexers, which cannot be reconfigured without a technician first disabling a fiber circuit. With the use of a piezoelectric material that steers the light from any number of incoming to any number of outgoing fibers, this new system will allow immediate restoration of service if a fiber goes down (also known as "backhoe losses").

Some companies have developed an optical switching multiplexer that uses the polarization state of liquid crystals to add or drop up to 64 wavelengths from a fiber. Other companies are considering arrays of thousands of microscopic mirrors that can tilt individually to send a wavelength down a chosen pathway. Alternatively, as previously mentioned, an electric field applied to certain materials may change the way light is routed. With yet another approach, called thermo-optics, application of heat to a polymer will block light from proceeding down one pathway but not another.

Good examples of hybrid switches that are in use today are the Star Switches from Astarte Fiber Networks. These products use a combination of sophisticated optics and electronics to perform the switching function. The Star Switch products allow for the configuration of one group of optical fibers as input fibers and another group as output fibers. The optical signal from each of the input fibers is focused into a collimated light beam through a lens. This beam is then automatically directed to the selected output fiber where the receiving lens focuses the light into the receiving fiber core. Light beams are then directed by the use of electronically controlled piezoelectric elements. The number of beams, at any time, equals the number of active communication paths. Signals are switched in less than 150 milliseconds by changing the direction of the light beam from the input fiber to a different receiving output fiber. Although light beams from different input fibers may intersect, there is no interference in the transmission of the intersecting beams.

To achieve low insertion loss and to ensure that each beam stays accurately directed, servo-control mechanisms are used to control and monitor all aspects of the switching process. This servo-control system eliminates the requirement for manual system calibration and optical alignment procedures. The servo-control continually checks all connections to eliminate outside influences of vibration and temperature fluctuations. The servo-control system operates both sides of the matrix and provides switch telemetry information to the main processors. The control system locks in fiber positions by continually verifying the acquisition of a target LED pattern. Switching commands can be entered by a line terminal, a DOS or Windows-based personal computer program, or with a network management program like simple network management protocol (SNMP) or HP OpenView.

CHALLENGES

Significant technical advances have to occur before this becomes a reality. Current roadblocks that need to be overcome by optical switching researchers include many factors:

- Lack of economical optical buffering,
- Difficulty of propagating very high-speed signals over significant distances,
- Absence of compact and economical light sources suitable for use in switches,
- Need to reduce loss and increase the ability of optical switches to be integrated to create large switches, and
- Need to reduce temperature sensitivity of optical switches.

In addition to such tricky problems, another factor for the delay in implementation is the fact that researchers seem to be travelling in many different directions toward optical switching and using many different types of exotic materials to build the components from which such switches will be constructed.

Even if optical cross-connects become universally accepted, telecommunications specialists see a continuing role for electrons, which may be needed to reshape light pulses that have attenuated over long distances and in monitoring networks. For example, there's no way to determine optically the number of bit errors on an all-optical signal.

CONCLUSION

Enterprises are experiencing an unprecedented increase in the volume of WAN traffic. Growth in the next two years alone is expected to exceed that of the past 20 years.

Photonic switches will avoid the costly burden telecommunications carriers now face-converting the multi-gigabit stream running on each wavelength into dozens or hundreds of lower-speed electronic signals, switching them and then reaggregating them onto a single light channel.

Huge telecommunications equipment companies and start-ups alike are now racing to develop all-optical switching products. Photonics has even become a basis for regional economic development. In October 1998, a group that combines the University of Texas at Dallas, several venture capitalists and major telecommunications equipment suppliers and carriers, announced the establishment of a Photonics development center based in Richardson, Texas, intended to attract new companies to the region.