The Future of Optical Networking

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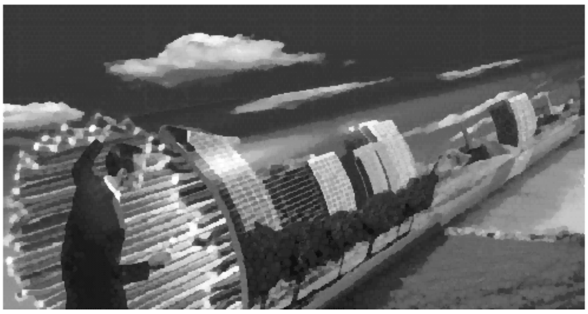
When Alexander Graham Bell, the inventor of the telephone, made the world's first phone call in 1876, the transmission rate was the equivalent of about 2,000 bits per second. He would be very astounded and proud to see how far things have come since then. In early 1998, a team of researchers in laboratories named in his honor demonstrated the world's first long-distance error-free transmission of one million million bits (one terabit) per second over a single optical fiber. But this is just the beginning. In the future, each wispy fiber may transmit close to an incredible 200 terabits per second. That's the equivalent of more than 3,000 million phone calls. This is truly astounding.



Although it might seem that this kind of capacity is well in excess of anything we could possibly ever need, this is not the case. In China, for example, it is planned to increase the number of installed telephone lines by approximately 300 million in the next ten to fifteen years. At the same time, there is an extremely rapid growth in cellular telephone users and an even faster growth in Internet users. This extraordinary growth is a worldwide phenomenon. In the last four years, the monthly traffic on the Internet has increased from 31 Terabytes (million million bytes) to 3,000 Terabytes and shows no sign of slowing. The International Telecommunications Union (ITU) estimates that the total number of Internet users will grow from about 60 million in 1996 to over 300 million by the year 2001.

Without a doubt, a revolution is taking place in the world's telecommunications networks. The question on everybody's mind is, "Where is this all leading to?" Specifically, what does the future hold for the optical network, which is at the core of this superhighway? This article will attempt to look into the future and consider three main aspects of the emerging optical network: applications, architecture and access.

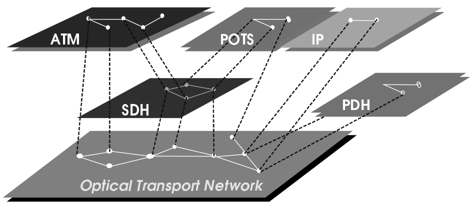


Figure One: *The Unifying Optical Layer*

THE FORCES SHAPING BANDWIDTH

No matter what application it is that is generating digital traffic, most of this traffic will be carried by the unifying optical layer (see Figure One). For this reason, the growth of various applications such as telephony (whether cellular or fixed), Internet, video transmission, computer communication and database access leads directly to an increase in the demand placed on the optical network. At the same time, advances such as dense wavelength division multiplexing technology (DWDM) – which enables systems to transmit different wavelengths, or colors of light, on the same fiber strand -- as well as market liberalization, are making bandwidth cheaper, and this is in turn encouraging the development of applications which require even more bandwidth. For example, it is quite likely that the optical network will be increasingly used to convey high-quality video. So that even though it might appear that the growth in traffic is very high at the moment, it will be even higher in the future.

The growing demand on the optical network is a complex issue. On the one hand, the capacity demand is extraordinary, and this in itself would be a big enough challenge to meet. However, this is accompanied by an increasing variety of services and applications as well as much more exacting requirements for quality differentiation. The quality of service provided by the World Wide Web (sometimes called the World-Wide Wait) is very different from the quality of service provided by the telephone service. For example, there is a vast difference in the quality requirement for a signal being used to transmit an emergency telephone call or live video coverage of a medical operation, as compared with an e-mail that is not urgent and can arrive after several hours. However, the same optical infrastructure is expected to support this wide variety of services. The future network, therefore, will have to be a managed optical multi-service network.

THE ROLE OF THE INTERNET

As has already been mentioned, Internet Protocol (IP) traffic is growing exponentially. In some parts of the world, it is expected that IP will constitute the majority of traffic in the near future. Therefore, in the longer term, packet-switched (as opposed to circuit-switched) communication will dominate, and existing networks will be progressively optimized to handle this type of traffic. Currently, there is a lot of discussion about transporting IP directly on DWDM and eliminating intermediate layers such as asynchronous transfer mode (ATM) and synchronous digital hierarchy (SDH). However, in reality, IP frames cannot be mapped directly onto DWDM at the present time. Most IP traffic in the backbone today is transported via ATM and/or SDH (or SONET) and these layers provide vital features currently not provided by IP and DWDM.

ATM networking provides:

- Unified format which allows single network for all services
- Guaranteed grades of QOS end-to-end
- Standards-based service maintenance
- Statistics and billing capabilities
- Intelligent, distributed provisioning and restoration of services

SDH networking provides:

- High-reliability facility transport
- Distributed high-speed facility restoration
- Circuit bandwidth management
- Advanced management and provisioning capabilities

The future will include a variety of protocols such as SDH, IP, Frame Relay and ATM, inter-working with DWDM. A lot of work is being done in the area of standardization and protocol inter-working. Protocol inter-working requires expertise in a broad range of disciplines. This is illustrated by the following true story: a team in Bell Labs investigating a procedure that had been defined for mapping IP onto SDH discovered that it contained a very serious drawback. It was shown that it was possible for a user to deliberately send killer "datagrams" (specific bit sequences) which could cause entire networks to fail within a few seconds. The team immediately drew the attention of the Internet community to this problem and proposed a solution which has been adopted in the meantime by the industry. Jon Anderson of Bell Labs comments, "It is interesting to note that the problem of transparency has been well understood for a number of years but clearly those involved in defining this standard were unaware of it."

Bell Labs has also proposed a new protocol called Simplified Data Link (SDL) to increase the efficiency of the way that IP traffic is transported through optical networks. Its basic purpose is to perform high-speed delineation of datagrams whose arrival is asynchronous. Bell Labs is investigating the use of SDL directly over SDH as well as WDM. SDL is primarily intended for point-to-point IP transport and has a number of advantages. It can be used with any type of datagram (e.g. IPv4, IPv6, etc…) and is well-suited to scale to higher speeds. The first integrated circuits that support this protocol have already been announced.

In spite of the considerably high enthusiasm for the Internet, traditional IP has a number of disadvantages, as any user of the Internet can confirm. Traditional IP equipment does not support quality-of-service. Current data networks have a high downtime and high operational expense. They will have difficulties with respect to meeting future requirements, particularly in terms of scale and added functionality. Also, the support of real-time communications needs is poor. However, a new generation of IP switches is emerging. For example, some IP Switches offer guaranteed, multiple levels of services that maximize the utilization of network resources, enabling mission-critical as well as lower-priority traffic flows to share the same infrastructure.

FAST-EVOLVING ARCHITECTURE

The second aspect of optical networking to consider is architecture, which is evolving rapidly. Features such as add/drop and cross-connection in the optical domain are being made possible by advances in photonics (see Figure Two). It will be possible to route signals flexibly through an optical network. Apart from saving costs, this will be especially useful for routing and protecting a wide variety of signal types individually. However, while more routing functions will be implemented in the optical plane, this does not replace the need for electronics. Even more sophisticated intelligence provided by electronics will be needed to manage the network.

Another trend is increasing integration. In an environment where a single fiber can carry up to 400 Gigabit/s of traffic, as is the case already today, it is clear that the systems connected to such fibers will require much larger capacities. The network elements of the future are therefore going to have a much higher level of system integration than they do today. It is not only a question of capacity, however. It has long been recognized that the nature of dense-wavelength-division multiplexing is well-suited to smoothly grow capacity to meet demand by adding wavelengths as needed, but in fact, DWDM has a further advantage, which is that the different types of traffic can be assigned different wavelengths, as required. A common uniform infrastructure does not imply that all services need to be carried through the network in the same way. By means of selective layered bandwidth management, IP/SDH, IP/ATM/SDH and ATM services can all exist in the same network and can be switched and routed as appropriate in the unifying optical infrastructure.

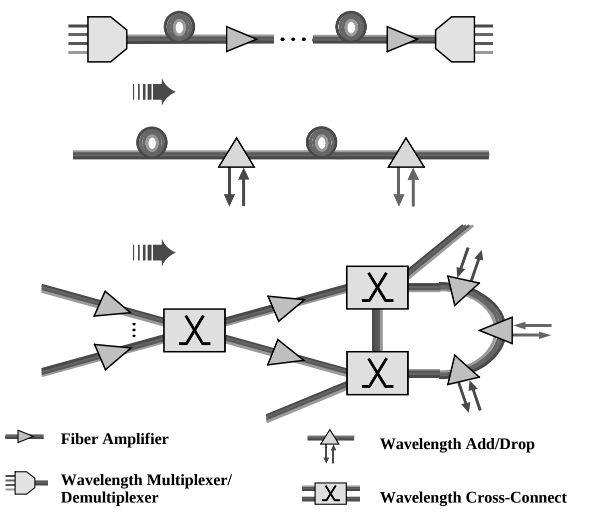


Figure Two: *The Evolution from Photonic Transport to Photonic Networks*

MOVING BANDWIDTH CLOSER TO THE END USER

The third aspect to consider is access to the optical network. Most users would like to have direct access to the optical network and the enormous capacity it provides. This will take place in stages. Multi-wavelength optical systems are rapidly spreading out from the core towards the end user. In regional and metropolitan areas, the requirements are somewhat different from the long-distance area. Metropolitan networks will use a greater number of wavelengths, operating at low to moderate bit rates (from 34 Mbit/s to 750 Mbit/s in addition to higher bit rates such as 2.5 Gbit/s and 10 Gbit/s), and the traffic is added and dropped at frequent intervals. Such systems must handle all types of traffic including ATM and IP. There is also a need for flexible architecture including remotely configurable full add/drop functionality and protection. Today's technology has reached the point where such systems are fast becoming a reality.

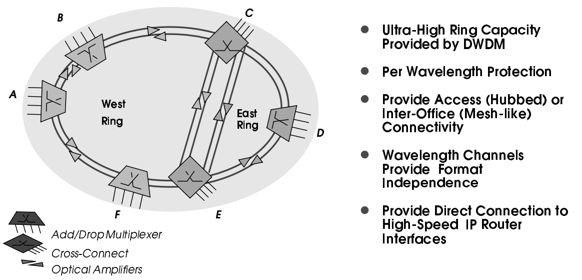


Figure Three: *Example of a Multi-wavelength Metropolitan Network*

The dream of fiber to the home (FTTH) or desktop is yet to materialize, mainly because of the cost-sensitive nature of this part of the network. In the near future, residential access may remain copper-based, using technologies such as ADSL to boost the capacity of traditional copper lines. However, for business offices, optical technology will be used to bring bandwidth to the end-user. Currently, a lot of Fiber To The Business (FTTB) networks are being deployed involving ATM and SDH access equipment at customer premises. The next step is using WDM technology for these applications. WDM will first be used in industrial and campus LAN environments.

The DWDM network at the Microsoft headquarters in Redmond is a good example of a trial of these latest technologies which use DWDM in the enterprise environment. We can choose to call this "Lightwave to the Business" (LTTB) and "Lightwave to the Desktop" (LTTD). The reason why this will become technically and economically feasible is the very large number of wavelengths that a single fiber can carry and spread the cost to more subscribers.

Advances in optical fibers are making the available transmission window much wider and it is expected that fibers will be able to carry more than a thousand wavelengths in the future. Historically, the wavelength region between 1350 and 1450 nm has not been used because of the high fiber attenuation over much of this region caused by the presence of the hydroxyl (OH□) ion. A residual impurity from the fiber making process, this ion causes an absorption peak near 1385 nm. Lucent recently announced a breakthrough in fiber for metropolitan applications, which eliminates the water absorption peak in the fiber's attenuation curve, and thus makes an additional "window" available for transmission. In effect, this makes the entire spectrum from 1300 nm to 1600 nm available for transmission. This much broader available window leads to a new concept which we can call "Broad Wavelength Division Multiplexing (BWDM)". Particularly for short-distance applications, where the need is for diverse signals at multiple bit rates, the signals can be transmitted using wavelengths that are not so closely spaced as in the ultra-dense wavelength division multiplexing used in long-distance transmission. This will make it possible to cost-effectively support various services such as high-performance computing, videoconferencing, broadband access (including wireless), multimedia and Internet.

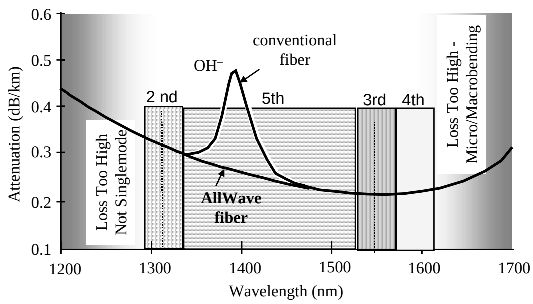


Figure Four: *Lucent's AllWave™ fiber eliminates the water peak, thereby increasing the number of wavelengths that can be used by more than 50%.*

CONCLUSIONS

We are at the beginning of a revolution in communications networks, where increasing capacity, variety of applications, and quality of service, are placing enormous demands on the optical network. However, advancing technologies such as fibers, selective bandwidth management, new-generation IP switches and increasing system integration will ensure that the optical network will rise to this challenge. The dynamics of ever cheaper bandwidth will spur innovations that will far outstrip what the spread of PCs has brought. The optical revolution is just beginning, and is advancing very swiftly towards a future online world in which bandwidth is essentially unlimited, reliable and low-cost.

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GLOSSARY

ADSL: Asynchronous Digital Subscriber Loop
ATM: Asynchronous Transfer Mode
BWDM: Broad Wavelength Division Multiplexing *(proposed term)*
DWDM: Dense Wavelength Division Multiplexing
FTTH: Fiber To The Home
IP: Internet Protocol
ITU: International Telecommunications Union
LTTB: Lightwave To The Business *(proposed term)*
LTTD: Lightwave To The Desktop *(proposed term)*
OLS: Optical Line System
PDH: Plesiochronous Digital Hierarchy
POTS: Plain Old Telephone Service
SDH: Synchronous Digital Hierarchy
SDL: Simplified Data Link
SONET: Synchronous Optical Network
WDM: Wavelength Division Multiplexing

Sando Anoff: Attended Imperial College of Science and Technology, London University, obtaining a degree in Electrical and Electronic Engineering in 1987. Since then, have worked in the field of telecommunications, focussing mainly on optical networking, first with Philips and later with AT&T Network Systems and Lucent Technologies. Currently located in Holmdel, New Jersey, working in the Optical Networking Group.

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