FROM E-BUSINESS INTO THE O-ZONE: DEVELOPMENT OF OPTICAL NETWORKS

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ABSTRACT

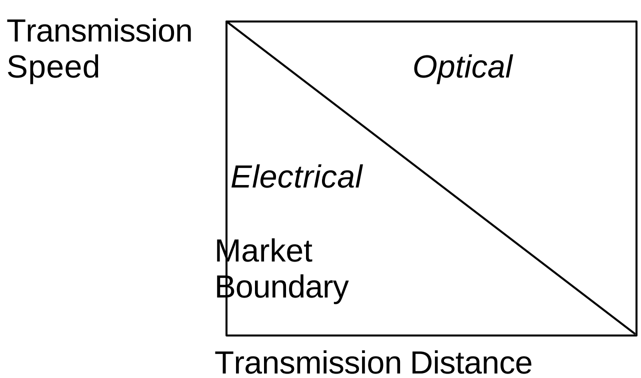
An increasing proportion of e-business and other network traffic moves over optical networks which provide higher capacity, speed, and security than electrical networks. An all optical network and even optical computing has been envisioned for 20 years, but technical characteristics of optical components have limited applications to the high end of networking, typically for speeds above 2.5 Gbps. While a fundamental advance in physics may be required for the implementation of an all-optical network, optics continues a steady advance into the network infrastructure. This paper describes the technical evolution of optical systems and examines the changing cost structure of optical systems that determines the size of the optical zone of operations (the o-zone).

Keywords: Networks, Optical Components, System Economics,

INTRODUCTION

Imagine starting your day in your own kitchen, finishing breakfast, then walking through a door into what appears to be a conference room where colleagues from thousands of miles away have gathered for what appears to be a face to face meeting. You sit your familiar computer terminal, accessing data over your computer terminal while discussing the results. When the meeting is done, you click a link on the screen and instantly move to what appears to be a room at your place of employment where you meet with other faculty or business associates. This is e-Business in a most elegant format. Many of the components to build this combination of the "holodeck" from the Star Trek series and a high-speed data communications system are already available for optical networks, but traffic management is proving to be one of the biggest obstacles. This section discusses the relative advantages that optical networks offer in achieving this virtual e-Business world, how optical networks have developed, and what remains as the major impediments to development.

Figure 1: Market Boundary for Optical and Electrical Networks



As illustrated in Figure 1, the market for optical and electrical networks can generally be defined in terms of transmission speed and distance. Optical networks dominate where transmission speeds are high and distances are long.

Optical systems also thrive in markets where security and resistance to outside interference is important.

As the following analysis will demonstrate, optical component costs continue to come down, encouraging migration of optical networks into operating zones once dominated by electrical systems generally pushing the market boundary separating the two technologies to the southwest in Figure 1. At the same time, the more familiar technology of electrical networks have allowed advancements there so that in some applications such as local area networks, electronics have actually claimed some of the relatively higher bandwidth applications that were once the province of the electrical systems.

The downside of being a "risk mover" [3], or early adopter, of fiber optic technology is demonstrated by the first all-fiber cable television installation in Alameda, California, in 1982. After on a few years of operation, the optical components were being taken out of the system and replaced with coaxial cable. The reason, according to a consultant who worked on the system design, was a change in fiber optic technology that occurred shortly after the system was deployed that created a new *de facto* standard [6]. New components in the old standard became difficult to find.. As a result of this rapid product innovation in the context of a network where components are often in place for decades, designers have been reluctant to use fiber optics even when they become cost effective. The following section outlines the rapid technological changes that have characterized optical systems.

OPTICAL SYSTEMS DEVELOPMENT

The principal application for fiber optic components has been to provide the physical guide for the use of a light source in a communications system. As a result, much of the early work in optical networks is attributable to AT&T. The company received the first patent for an optical system in 1934, but weak light sources and poor quality cables made practical applications infeasible.. In 1958 AT&T developed the laser by AT&T to improve the light source. At about the same time interest developed in the use of glass rods for image transmission. Applications in medicine resulted in the bier scope that was used view internal parts of the body. Corning Glass led much of the commercial research to develop glass fiber the conducted light waves with little signal distortion.

Military applications accounted for most commercial applications of fiber optics during the early 1970s, with basic research continuing at AT&T's Bell Laboratories. Much of the military's interest in fiber optics as a communications system has been that, in spite of the higher cost, fiber optics are less sensitive to outside interference than electrical systems. For example, a potential enemy would have a much harder time in disrupting a ship's internal communications if they were based on fiber optics.

The year 1978 marks the beginning of wide scale product development with the first significant entry into the telecommunications market when fiber optic cables were installed in the New York telephone system. An important reason for the choice of bier at that time was the sever space limitations in the city's underground ducts, filled to capacity with bulky copper cables. In less than 10 years, New York Telephone went from a copper-based analog network to a fiber optic and digital network. By comparison, the generation of technology prior to 1978, the copper-based analog system prevailed for almost 100 years. Replacing another large portion of the telephone system, the subscriber loop, represents a major market window that has been just out of reach of optical networks for about 20 years.

The first generation of commercial optical systems, beginning in 1978, were standardized on 800-900 nanometer (nm) wavelength range with light sources generated using gallium arsenide (GaAs) based components. These components were adapted from recent military applications that were generally designed for short distance communications at relatively low speeds. As transmission distances and speeds increased, the wavelength used for optical systems has generally lengthened. Longer wavelengths supported longer transmission spans and higher transmission rates.

The second generation of fiber optics was standardized on 1300 nm components and the injection laser diode (ILD) that proved to be a cost-effective light source at the longer wavelengths. Some manufacturers continued development in the 800-900 nm wavelength range with the goal of reducing system cost and complexity. This effort was considered important in competing against electrical systems

The 1300 nm wavelength continued into the third generation with major advances in optical component price and performance. The use of semiconductor technology to develop the PINFET receiver allowed manufactures to replace the expensive lasers that had been used for transmission with the less costly and more reliable light emitting diode (LED). The development of the new single mode fiber allowed for longer transmission distances.

The fourth generation moved wavelengths up to the 1550 nm and 1630 nm standards which seem to be the limit for improving system performance through the use of higher wavelengths. These standards are expected to continue into the foreseeable future. Receiver component costs continued to decline with the development of the avalanche photodiode (APD).

The fifth and current generation of optical components has marked by advancements in cable efficiency with the use of eridium doped fiber (EDF) to reduce signal degradation and by the integration of other components such as transmitters, receivers, and connectors.

The next generation will likely be based on opto-electronic integrated circuits (OEICs), as designers struggle to adapt optical components to the granular nature of local traffic.

CURRENT DEVELOPMENT ISSUES

Optical components have been used for point-to-point backbone support in networks. The problem of traffic management has been left to the electrical components, such as switches and routers. Network experience with using switches to manage traffic dates back to the 1870s, so the technology is well developed and understood. Now, however, the conversion of optical signals to electronic signals for switching, routing, and local delivery presents a major bottleneck in network development. The packet-switched technology used in the internet was designed for an electrical network, where bandwidth is limited and traffic management hardware is relatively cheap. As a result, the protocols that have developed create problems for optical technology where bandwidth is relatively cheap and traffic management hardware is undeveloped.

The volume of traffic supported by optical networks, measured in terabits per second, makes it uneconomical for routers and switches to detect individual traffic destinations [4, 2]. Traffic needs to be aggregated, as with commuters boarding airplanes at the airport to travel to an airport destination that is not the final destination for their trip. A new internet protocol may need to be developed where addressing includes not only origination and destination, but also some intermediate locations where traffic is aggregated.

OPTICAL COMPONENT PRICE TRENDS

Table 1 contains prices indexes for major optical components calculated from historical average sales prices and a forecast for future price trends. Much of the market acceptance for optical components can be attributed to the dramatic price reductions that improvements in technology and manufacturing economies of scale have contributed since the first commercially available systems in 1978. There is a substantial literature on forecasting prices for technical products with the logistic and Gompertz transformations getting much of the attention [1,5,8,9]. The estimates of future prices in the table below were developed using the following equation:

$$Y_{t+1} - Y_t = B_o + B_1 Y_t + B_2 Y_t^2 + B_3 X$$

where,

Yt = Ln(It/(1 - It)) for Ln (the natural log) and It the price index in time t
Bi = estimated parameters using least squares against historical data
X = the average product life of each component

As the table suggests, prices of standard optical components at from three to ten percent of their per unit average price in 1978. Prices are expected to follow this downward path into the near future since there are no serious technological barriers in the way of improved component efficiency. The promise of continuing even higher transmission capacity and falling prices have captured the imagination of network designers.

THE DEMAND FOR TRANSMISSION SPEED

The growth of e-Business and other wide area network applications has resulted in a rapid increase in network traffic. The online virtual reality application described at the beginning of this article will be one of the most data intensive applications expected for future networks. One study [7] indicates that 3-D holography, telepresense, and online virtual reality could add 80,000 terabits per second demand to the U.S. network infrastructure. Web agents and metacomputing applications could each add another 200,000 terabits per second. At present, however, transmission capacity exceeds transmission demand by about 10 terabits per second, so companies faced with making profit targets for the next quarter are understandably less optimistic about future demand.

Table 1: Historic and Estimated Price Indexes for Optical Network Components

	Cable	Multiplexer	Transmitter	Receiver	Connector	Coupler
Year						
1978	1	1	1	1	1	1
1979	.89	.91	.86	.086	.88	.91
1980	.81	.83	.7	.069	.85	.75
1981	.66	.77	.63	,6	.73	.6
1982	.55	.69	.52	.47	.63	.47
1983	.46	.62	.47	.43	.56	.38
1984	.43	.57	.43	.39	.51	.31
1985	.38	51	.37	.3	.47	.25
1986	.33	.47	.33	.22	.44	.2
1987	.29	.41	.29	.17	.4	.18
1988	.24	.37	.24	.14	.35	.16
1989	.22	.33	.2	.12	.31	.14
1990	.19	.29	.17	.104	.27	.13
1991	.14	.26	.16	.088	.24	.11
1992	.11	.23	.14	.081	.21	.1
1993	.102	.19	.12	.070	.19	.092
1995	.084	.17	.11	.058	.18	.087
1996	.065	.15	.09	.049	.16	.074
1997	.051	.13	.081	.044	.14	.062
1998	.044	.12	.073	.032	.12	.048
1999	.032	.104	.062	.025	.11	.041
2000	.029	.092	.058	.022	.104	.033
2001*	.025	.089	.051	.021	.099	.025
2002*	.022	.082	.048	.019	.096	.022
2003*	.020	.074	.047	.017	.091	.019

*** Forecast**

CONCLUSION

A number of research initiatives to develop optical switches and routers have been supported in the academic and private business communities in anticipation of new services that will require significant expansion of existing network capacity. The promise of an impending all optical network and elaborate network demand has been with us for 20 years, and as a result many business planners have become pessimistic about the near term economic viability of these technologies. Although there is some question about timing, the inexorable growth of network traffic dictates that optical components will continue to expand into the network infrastructure.

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