PROGRESS IN OPTICAL COMMUNICATIONS FOR COMMERCIAL TERRESTRIAL TELECOMMUNICATION NETWORKS

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ABSTRACT

The past decade has witnessed many advances that have considerably improved the capacity, span length between regenerators, network reliability, survivability, and flexibility, as well as moving optical technology to the local loop to provide cost effective multimedia services to subscribers. The device, component, and network architecture advances that resulted in this progress will be described.

INTRODUCTION

The past decade has witnessed continued very large growth in the performance, implementation, and breadth of application of optical communications in commercial terrestrial telecommunication networks. Although this growth was forecasted, the primary approaches used in the current state-of-the-art, in many cases, followed different paths than those envisioned ten years ago. This paper will present a review of the progress that has been made and will also speculate on significant areas of research that play a role in the next decade of fiber based telecommunications networks. The progress will be discussed for two major areas of the network; WANs or wide area networks, which include the long haul, high capacity transport of multimedia services and traffic, and MANs or metropolitan area networks, which include local exchange interoffice trunking, local loop, and subscriber distribution of multimedia services.

PROGRESS IN WANS

The commercial fiber optic long haul transmission system of the mid 80's used single mode fiber and Fabry Perot laser diode sources to transport 9 to 12 asynchronous DS3 signals (44.736 Mb/s per DS3) on a 1.3 micron wavelength carrier. The laser was directly ASK modulated by a 400 to 560 Mb/s data stream produced by multiplexing the DS3 signals, required stuffing, framing, and overhead bits for alarm, control and network management. Each manufacturer of this equipment utilized their own proprietary protocols for the transmission bit stream. The typical span length between regenerating repeaters was about 40 Km.[1]

Issues that had to be addressed to meet the growing market demand for high capacity, long haul transmission, the 1985 approach to resolving these, and the current approach are summarized in Table 1.

The actual approaches used during the past decade differed considerably from those considered in 1985. The differences illustrate the very dynamic nature of lightwave technology.

Heterodyne systems [2] demonstrated in the early 80's exhibited sensitivities 10db better than the best high speed direct detection systems. However the heterodyne systems were inherently complex, tended to be costly and difficult to implement, and were polarization dependent. The erbium doped fiber amplifier (EDFA) which amplifies at 1.55 micron wavelength [3] when pumped with 0.98 or 1.48 micron light became commercially available during the past two years and proved to be a much better solution to the improving the loss limit of very high speed fiber. The device has excellent performance as a power amplifier capable of increasing typical DFB laser transmitter power by 10 dB, and as a low noise amplifier with noise figures approaching 3dB, with linear gains of 30 dB. A nonregenerating repeater is made by cascading the above two amplifiers. The performance reached the levels of the heterodyne case, but with considerably simpler

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systems and EDFAs are currently being used in commercial systems.

One of the shortcomings of the EDFA is that it only operates in the 1.55 micron band. Research is underway on alternate rare earth doped silica fibers with energy band structures suitable for 1.3 micron operation, but to date no practical amplifiers have evolved although gain has been demonstrated at 1.3 microns in the lab using praseodynmium doped fibers.

EDFA's have a well defined role in new installations that incorporate dispersion shifted fiber optimized for 1.55 micron operation. However much of the existing fiber installations utilize fiber optimized for 1.3 micron operation. It is not economically feasible to replace the existing fiber which would be severely dispersion limited at 1.55 micron propagation. As a consequence considerable research [4] has been conducted to develop dispersion compensation approaches or equalizers that remove the dispersion penalty and permit high speed transport of 1.55 micron light using the 1.3 micron optimized fibers.
Both electronic and all optical dispersion compensation schemes have been developed. The various compensation schemes use EDFA's spaced about every 30 - 40 Km to overcome the loss limit, and all show very reasonable performance. At this time the dispersion compensating fiber is the favored approach since it is relatively simple and low cost.

Improvements in the linewidth of laser sources have played a significant role in the increasing the dispersion limit of systems. The 0.5Gb/s systems of the mid 80's were the last moderately high data systems to utilize Fabry Perot (FP) laser diodes. The 2-3 nanometer linewidth FP diodes in the presence of chirp were intolerable as sources for higher data rate transmission. DFB lasers used in the lab during the early 80's produced some remarkable results on 8 GB/s demonstrations, but in commercial service the performance was limited to the range of 2Gb/s operation, primarily due to chirp broadening. In the latter 80's and early 90's improved DFB diodes and in particular multiple quantum well DFBs with excellent chirp susceptibility [5] were introduced and enabled directly modulated operation at multi Gb/s rates. Today narrow linewidth sources using external cavities or multiple cavity lasers are rarely mentioned. However for very high data rate systems exceeding 5 -10 Gb/s, the external modulator remains as a viable contender. New modulator structures based on quantum well devices appear to have excellent promise.

Several major outages were encountered during the 80's on large fiber networks due to fiber cuts and fire in a large terminal building. Because of the large number of subscribers and revenue base involved, it was apparent that the protection and service restoration used for conventional cable systems were no longer valid for the very high density of subscribers on the new fiber systems. To address the survivability issue new networks topologies based on the use of high capacity digital cross connect switches (DCS) that permitted rerouting of network traffic were developed and implemented. While the current DCS's operate at DS1, DS3, or SONET STS-1 data streams, in the future optical cross connect switches will be used to move traffic directly to an alternate fiber path.

In addition to network rerouting over diverse paths with DCS's, new topologies [6] such as ring networks, were introduced to allow self healing in the presence of fiber cuts. Two fibers are used in the ring and all terminals in the network are distributed along the ring. With normal conditions, transmission may be clockwise around the ring, but when a fault occurs, transmission at the terminal closest to the fault is transferred to the second fiber of the ring with transmission in the counterclockwise direction to maintain communications in the presence of the fault. The ring architecture is used in all parts of the network.

As the quantity of equipment used by carriers grew, it became apparent that multiple sources of supply was a necessity and that to effectively do this would require a new transmission standard. The new standard SONET or *Synchronous Optical Network* for North America and a similar standard, SDH, for Europe was developed[7]. SONET brought many new advantages in addition to allowing multiple sourcing and global compatibility in the upper levels of the hierarchy. Included are simplified drop and insert of signals at terminals and intermediate sites, advanced network management and control features, compatibility with existing network transmission standards, and suitability for advanced broadband network transmission. The hierarchical levels of the new standard are listed in Table 3. Note that the higher bit rate levels follow the law 51.84 *N Mb/s, where N is an integer, since these levels are formed by interleaving of bytes of the lower levels.

PROGRESS IN MANS

Major changes took have taken place in metropolitan area networks. Fiber systems were introduced during the late 70's and early 80's in the local loop for interoffice trunking between Central Offices. By the mid 80's fiber digital loop carriers and distribution systems that extended from the Central Office to the Remote sites, where wire facilities to several thousand subscribers were terminated and subscriber analog signals were digitized and formatted in the T1 protocol, were widely used.

The final phase of the introduction of fiber into the loop, extending the fiber to a distribution point close to the subscriber's premises (fiber to the curb, FTTC) and providing broadband service to subscribers over a metallic facility is now undergoing field trials and initial implementation, but the architecture and approach has been under study for more than a decade. There are a number of architectural approaches that are still candidates to provide the broadband service.[8]

The issues regarding fiber in the loop now take on more importance in view of the new legislation embodied in the 1996 Telecommunications Act that opens previously separated market areas to competition. Under the new law, the service base of local telephone, CATV, and long distance carriers is extended to permit each to become a competing carrier of multimedia services including telephone, data, and broadband entertainment video to subscribers, and also to provide long distance services.

The 1985 issues for fiber in the local loop and the current approaches to resolving these issues are shown in Table 3. The cost of implementing fiber in this application has always been an important challenge since any new approach used will have to be competitive with the mature twisted pair connectivity . It appears now that by using the advances made possible by passive optical network distribution [9] this objective may finally be met.

Early configurations of the fiber distribution to subscribers centered on optical terminations at each subscriber. Because of cost issues and powering concerns, the most popular approach today is to use a network interface unit that terminates the fiber on the network side and fans out to 10 to 30 subscribers over a metallic facility on the subscriber side. The optical network termination has both an optical transmitter and a receiver to accommodate up stream and down stream traffic. Information is directed to the appropriate subscriber through digital addressing. Ringing power is provided to the subscriber over the metallic facility.

Currently there are two competing technologies to deliver broadband services to subscribers, the Hybrid Fiber Coax system (HFC), and the Switched Digital Services (SDV) system.

The HFC system typically uses a 50 to 750 Mhz spectrum placed on an optical carrier to deliver information to subscribers, and a 5 to 40 Mhz spectrum for subscribers to communicate to the network. RF modem technology (QPSK or M-Ary QAM) is used to place digital voice and data on RF carriers which are multiplexed with the RF carriers used for analog video. This mixed spectrum is then used to modulate a very linear DFB laser for transmission to subscribers. 70 to 100 analog video channels and the additional services may be delivered to 100 to 2000 home areas. The distribution from the central office is on optical fiber to a fiber/power node where the final drops to the customer interfaces are made over coax cables. The video channel selection is made using a set top box .

The favored SDV architecture today uses two networks to deliver the full broadband services including switched video on demand, data, and voice, all in a multiple digital format over one network, and analog video channels on a second network. Both networks utilize fiber distribution from the analog video headend and the digital office server respectively. The analog video is handled similarly to the HFC and provides video service over a coax line that terminates at a set top box. The switched digital service fiber terminates at an optical network unit that serves 20-30 subscribers over twisted wire pairs. The twisted wire pairs can provide high speed operation by the use of digital signal processing. Symmetric DSP service for two way operation is commonly called HDSL and asymmetric one way operation is called ADSL.

The multi media switched voice, data, and video is transported, switched, and multiplexed in a packet format called Asynchronous Transfer Mode (ATM) that is specifically designed to meet the requirements of broadband, bandwidth on demand flexible service[10].

The HFC system is currently lower cost than the SDV but is more susceptible to noise ingress. The SDV system provides more bandwidth to subscribers and has a wider range of applications.

CONCLUSION

The use of optical communications for terrestrial networks continues to evolve, making use of the high speed, high capacity capabilities of fiber transmission.

TABLE 1

ISSUES & APPROACHES FOR NEXT GENERATION WAN'S

ISSUES	*1985 APPROACH*	*1996 APPROACH*
Capacity	WDM	WDM (>200Gb/s)
Loss Limit	1.55 Micron Band Heterodyne System Flouride Fiber	1.55 Micron Band EDFA
Dispersion Limit	Disp Shifted Fiber DFB Lasers External Modulator External Cavity	Disp Shifted Fiber Disp Comp Fiber MQW DFB Lasers External Modulators
Network Reliability	Diversity Routing	New Architecture Ring Networks DCSs
Proprietary Equipment	New Standard	SONET

TABLE 2

SONET HIERARCHY

OCN	OC1	OC3	OC12	OC48	OC192
Data Rate Mb/s	54.84	155.52	622.08	2488.32	9953.28

TABLE 3

ISSUES & APPROACHES FOR FIBER IN THE LOOP SYSTEMS

ISSUES	*1985 APPROACH*	*1996 APPROACH*
Cost	Reduce Cost of Optical Cmpts	Reduce Cost of Optical Cmpts New Architecture Passive Optical Networks
Power	Fiber to the Curb	Fiber to the Curb
Bandwidth Metallic Link	Narrowband: Twisted Wire Pair; Broadband: Coax	HDSL, ADSL Coax
Survivability of Services	Not Addressed	New Architectures

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