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High Bit Rate Digital Subscriber Line: A Copper Bridge to the Network of the Future

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***Abstract*—The high-bit-rate digital subscriber line (HDSL), permitting low-cost 1.5 Mb/s copper access, will ease the transition to fiber access by accelerating the use of higher speed services. Copper will dominate over fiber customer access for at least the next ten years. During this period, the success of high-speed switched services will depend on the connectivity provided by both fiber and copper access. HDSL will initially be used to serve private-line DS1, ISDN primary rate access, and digital loop carrier feeders. Later, the HDSL will be applied to switched services such as metropolitan area networks (MAN's) and circuit switched DS1's.**

I. INTRODUCTION

FIBER optics, long popular for transmission between switching centers, is now widely endorsed as the transmission technology of choice between the switching center and the customer site. The fiber optic technology being developed now will be the most economical means to build new access facilities to customers using plain old telephone service (POTS). More importantly, fiber optics are essential for the success of broadband telecommunications services. Telephone companies are rapidly deploying fiber optic cables in the access plant today. But, the enormity of the existing local access network will make the fiber optic facilities a minority of the local access for many years. The powerful economic pressures for reducing transmission costs and providing broadband services raise serious concerns about the next twenty years required to fully deploy fiber. We suggest that while maximum use is made of the fiber as it is deployed, we must also make the best use of the existing $100 billion copper cable plant in the U.S. The high-bit-rate digital subscriber line (HDSL), permitting low-cost 1.5 Mb/s copper access, will ease the transition to fiber access by accelerating the use of higher speed services.

II. AN ILLUSTRATION: PHOTOWN

The upscale suburban community of Photown typifies the communications revolution of the mid-to-late 1990's.

The same fiber-to-the-curb network that provides POTS to Photown's homes and businesses carries a powerful set of advanced services at a modest incremental cost. The smallest business sites have access to switched computer communications at throughput rates that were once possible on only the largest private networks. Medical clinics access multimegabit x-ray and CT images from remote hospital record centers in a matter of seconds, and a variety of other bitmapped and coded image formats are revolutionizing applications ranging from computer-integrated manufacturing to the preparation of advertising copy. Even routine business paperwork is being automated with computer-aided workflow systems based on scanned business documents.

Local hotels have equipped many of their meeting rooms to support the growing demand for video conferencing, and medium to large business sites typically have video facilities of their own. Many video services for home and business customers require full video transmission only "downstream," to the user, with simpler interactions using voice and low-speed data and control signals providing all of the needed interaction in the "upstream" direction. These applications, including training and education services, library access to multimedia materials, and a growing number of public services, are deployed even more widely than videoconference facilities, penetrating individual offices and many residences. A growing body of material is being developed for these applications on optical storage media, accessible over the network at disk-transfer speeds.

Photown is growing rapidly, as the needs of a growing service economy create strong demand for a modern communications infrastructure. Despite the virtually unpredictable growth pattern created by the work-at-home phenomenon, the Photown Telephone Company has little difficulty adjusting to new service demand wherever it springs up. Any line can be upgraded to advanced service

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capability with the addition of the right terminal equipment at the subscriber's site and a high-speed connection at the local exchange office.

III. What's Wrong with This Picture?

For an imaginary location, Photown has had a lot of visitors. Minor variations on the scenes described above appear regularly in network-of-the-future articles in the communications trade press, timestamped anywhere from the mid-1990's to the turn of the century.

Forecasts of this sort are based—in part—on valid technical information. In volume production, known designs for fiber-to-the curb telephone systems could be cheaper than traditional copper telephone loops for most new construction in the 1993-1995 timeframe. These systems could deliver all of Photown's advanced services at reasonable cost, as well as providing an excellent platform for the evolution of even more powerful applications in the early 21st Century. The only problem is that there might not be anybody to talk to at the other end of the high-speed call.

Fiber optics will replace copper in the local telephone loop, but not all at once. The construction budget of a local exchange carrier (LEC) can support only a modest deployment of new cable plant each year. A typical LEC, devoting 100% of its new-construction budget to installing fiber, would take about twenty years to reach 50% of its customers with fiber-optic local service. Even if all rehabilitation projects were added to the fiber deployment, it would still take nearly twelve years to reach 50% fiber penetration. New service opportunities could accelerate this process, but there would still be a long delay between the first fiber deployment and widespread availability of high-speed services. Fig. 1 illustrates the length of time it will take to replace copper transmission with fiber optic systems. Though fiber optic cable can be economically proved-in for POTS alone, the most exciting potential lies in the provision of higher speed services. The success of these services depends on connectivity within a large community of interest.

The first fiber optic communities—the Photowns of the world—will be islands of high-speed services. Photown residents could easily be equipped for wideband communication of computer data, digital images, and interactive video to one another, but calling would initially be confined to a small number of sophisticated customers. The resulting market for wideband information services could hinder the attraction of service providers. Photown will have high-quality telephone service and a cost-effective implementation of narrowband enhancements such as ISDN, but wideband "network of the future" services will have to wait for the rest of the world to come on line[1].

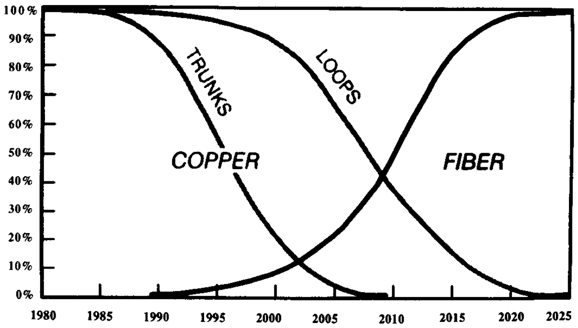

Fig. 1. Conceptual model of fiber deployment.

IV. The Missing Link

What would it take to bring wideband services to the world at large? The ideal solution would be a low-cost transmission system that could instantly convert any existing local telephone connection to a wideband channel. No changes would be needed in the outside plant; the line termination equipment would simply be upgraded at both ends of the loop, with relatively simple electronics. If this could be accomplished with a line termination of about two to three times the complexity of a basic-rate ISDN NT1, advanced services could be affordably deployed wherever a significant business opportunity exists—independent of geography.

The service would not need to operate at SONET broadband speeds. *All of the services described in the Photown fable could be implemented over digital lines at the DS1 data rate of 1.544 Mb/s.* However, the current T1 carrier technology for delivering DS1 service would not meet the needs of a new mass communication service because of its high cost, special requirements on the subscriber's inside wiring, and long, complicated network provisioning process. For low-cost and timely provision of service, there is a need for existing telephone lines to transport DS1 data rates without regard to repeater placement, cable-pair placement in a particular cable binder group, or its configuration of bridged tap wiring.

We are closer to that solution than is commonly believed. In November 1989, Ameritech conducted experiments together with Bellcore and one of our major equipment suppliers, in which prototypes of a new transmission technology known as HDSL (high-bit-rate digital subscriber line) successfully carried DS1 signals over carrier-serving area distances on existing Illinois Bell telephone loops. The loops were not conditioned in any way, and they included some transmission challenges, such as bridged taps, that have caused problems with other so-

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[1] It would be an exaggeration to say that there would be *no* application of wideband communications, but the applications would be limited to special services within a narrow community of interest until fiber deployment reaches a critical mass. Based on Fig. 1, this process could take one to two decades.

phisticated signal formats. The HDSL system provided excellent transmission over these facilities, and an application demonstration delivered a high-quality videoconference signal over a distance of 12 000 feet to the serving exchange office.

HDSL is an outgrowth of transmission techniques that were developed for ISDN basic rate access and high-speed digital modems. While several different detailed implementations of HDSL are currently under consideration[2], they all share the following basic characteristics.

- Transmission over existing distribution wire pairs.
- Full-duplex, DS1-framed transport at 1.544 Mb/s.
- Specified bit error rate ten times better than T1 carrier.
- Repeaterless operation for full carrier serving area (CSA)[3].
- Operation in the presence of bridged taps and gauge changes.
- Spectral compatibility to permit coexistence in the same cable-sheath with voice, basic rate ISDN, T1 carrier, and many other transmission systems.

Today, HDSL is still a laboratory system, but it could be put into full-scale deployment in about two years. Some hard work remains to be done in the negotiation of transmission specifications and the development of operations plans for full-scale deployment. Yet, the feasibility of HDSL is well established.

Upgrading a copper phone line to HDSL will not be quite as inexpensive as providing DS1 service via fiber to people in Photown, but the cost and provisioning of HDSL will make it attractive for most of the services described in the fable. And since most potential customers will be within reach of HDSL on the day it is introduced, mass-market wideband services will not have to wait for large-scale fiber deployment.

HDSL deployment can lead to the emergence of wideband service demand, because the technology can be proven-in with benefits to current services: private-line DS1, ISDN primary rate access, and digital loop carrier feeders.

V. What About Switching?

HDSL can connect a mass market to the nearest telephone exchange at wideband data rates, but where will the signals go from there? Most of the services described in the opening fable will require wideband switched connections, not just cheaper DS1 private lines.

Fortunately, a complementary technology is likely to become available in the same mid-1990's timeframe as HDSL. Metropolitan area network (MAN) systems, initially developed to provide a limited number of connections at DS3 and higher speeds for major sites in downtown areas, have proven to be even more effective as DS1 data switches for a larger subscriber base. MAN's provide an excellent switching platform for DS1 data communications, digital image transmission, and real-time interactive video. The main limitation that has been anticipated for these services is the small number of subscribers with DS1 access to the exchange—and with HDSL, that number can grow rapidly.

A second wideband switching technology is also near readiness: circuit switching of DS1's and fractions of DS1's that function much like and ISDN B-channel call, but at a 1.544 Mb rate.

The residents of Photown may not be so isolated after all.

VI. Back to the Future

A natural question to ask at this point is whether there is any remaining need to build Photown in the first place. If HDSL can deliver wideband service on proven copper transmission media, and MAN's and DS1 circuit switching systems can switch that service efficiently, is there any reason for telephone companies to work their way through the learning curve for optical transmission and more advanced switched services such as broadband ISDN?

HDSL provides a good vehicle for the widespread deployment of DS1 services, but it is pressing the limits of transmission over twisted-pair wire. Fiber optic transmission, once installed in an area, will always offer a cheaper upgrade to DS1 service, and its ability to carry signals hundreds of times faster than DS1 makes it a better long-term investment. As fiber loop technology reaches cost parity with copper for POTS, it would be a mistake not to use it in new construction and major repair. As the demand for advanced DS1 services develops, the economics will tilt more strongly in favor of fiber, eventually justifying early replacement of copper with fiber in areas that would not otherwise qualify for traditional loop rehabilitation.

HDSL does not make Photown obsolete; it makes Photown practical. The development of a large-scale market for switched DS1 services will similarly accelerate the deployment of 150–600 Mb/s broadband ISDN switches. The first use of 150 Mb switching will probably be for tandem switching of multiple DS1 channels concentrated by MAN's. Once deployed, these switches may also provide broadband ISDN services for leading-edge subscribers.

The network of the 21st Century will have a number of the characteristics that we have seen in the popular forecasts of the last several years. Broadband ISDN services,

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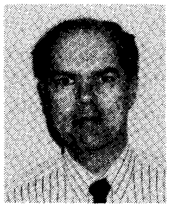
[2] T1E1 proposals for HDSL implementation include: one-pair QAM transmission with trellis coding (AT&T), two-pair 2B1Q (separate proposals by Bellcore and BNR), two-pair multitone transmission (J. Cioffi, Telebit), and combined coding-precoding (Motorola/Codex).

[3] The CSA permits loop lengths up to 12 Kft of 24 AWG cable, or 9 Kft of 26 AWG cable.

delivered via fiber-optic local loops, will integrate a broad range of voice, data, image, and video services to the business and (eventually) residence markets. Universal broadband communications will provide the basis for a rich market in information and entertainment services.

Copper loops with HDSL technology are a necessary evolutionary step towards a broadband fiber network. Wideband copper transmission is not the ultimate network of the future. It is the bridge that will get us there.



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He was a Member of Technical Staff at AT&T Bell Labs in Naperville, IL for 12 years, where he worked on 1AESS circuit design, memory updating systems, 5ESS ISDN circuit design, system architecture, and ISDN standards (ISDN basic rate, layer 1). He joined Americh Services, Inc. in May 1988, and is now a Senior Member of Technical Staff in the newly formed Advanced Network Technologies organization. Shortly after joining ASI, he was elected Chairperson of the United States Exchange Carriers Standards Association Standards Working Group T1E1.4, which is responsible for layer-1 network interface standards for ISDN basic rate (the U-interface (2B1Q) and S/T interfaces). This group also has a project to study high-bit-rate digital subscriber line (HDSL) technology which will permit nonrepeatered 1.5 Mb/s service over existing nonconditioned CSA wire loops. He leads a project team within Ameritech to study this technology. He is also investigating next-generation switching architectures, which include refinement of ISDN and planning towards 1.5 Mb/s (and $N \times 64$ kb/s) switching. He participates as a U.S. delegate to the CCITT SG-XVIII International Standards body to help carry the U.S. standards positions into the international standards bodies. He holds five U.S. patents.