CAN OPTICAL FIBER COMPETE WITH COAXIAL CABLE?

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ABSTRACT

This paper concentrates on two major issues in comparing the optical fiber and coaxial cable media:

1. the relative capability of delivering a wide range of telecommunication services, and

2. comparison of the cost-effectiveness of the resulting coaxial network with the most likely future alternative, the switched optical fiber network.

It is shown that the coaxial cable medium has certain natural advantages over the switched approach which lead to significant cost advantages for the coaxial medium.

INTRODUCTION

There are currently over 600,000 miles of coaxial cable plant passing over 50 million homes in the United States. It is projected that about 50,000 miles of new plant will be added in each of the next few years, with new construction tapering off substantially by 1988 or 1989 as all major markets are wired. It appears that existing plant is being rebuilt at the rate of about 20,000 miles per year (1).

Since the outside plant of a CATV system is expected to have a ten to fifteen year useful life, cable operators must deal with the following serious business issues:

1. How can profitable growth be achieved with the existing large base of relatively new embedded plant?

2. Is there a different medium that should be used for future new or rebuilt plant that will lead to a more profitable future?

Although industry growth, and growth of certain cable companies, can be achieved over the next few years by marketing existing cable services to the new homes passed, growth beyond this time frame would seem to depend upon developing additional revenue streams. Since franchising competition has led to larger capital investments per subscriber than a few years ago, new revenue streams are probably required just to achieve traditional returns for new systems.

This paper assumes that the revenue streams of interest are most likely to come from enhanced telecommunication services having wide appeal. Delivery of such services would result in using the CATV plant as the local loop of a wideband integrated telecommunications network. Specifically not discussed here is reduction of the operating cost side of the profit equation for current CATV services. This author is unaware of any way in which using a medium other than coaxial cable would lead to such cost reductions. Indeed, the cost-effectiveness comparison presented later would indicate that operating costs would be likely to rise for other media.

BACKGROUND

A traditional cable television system has three major components, as shown in Figure 1. The hub, or headend, is the central collection point for all signals. These signals are combined and sent out over the coaxial cable plant, eventually reaching subscribers' homes where they are converted in frequency by the home terminal unit (also called a converter) for reception by the customers' television set.

The cable plant fans out from the hub in a tree fashion, splitting and resplitting until all homes are passed. This topology, called tree-and-branch, is characterized by the fact that all of the signals on the plant, or at least on each trunk, pass all of the homes served by that trunk and its branches. Thus, all bandwidth on a trunk is shared by all of the homes served by the trunk.

A cable system built within the last few years will use distribution plant capable of delivering high quality television signals to all homes served using signal carrier frequencies up to at least 400 MHz, with 440 MHz being even more typical recently. Downstream signals (hub to home) are typically carried on frequencies above 50 MHz, with frequencies from 88 MHz to 108 MHz set aside for broadcast FM radio. Such modern systems will also have amplifiers installed to carry signals in the upstream direction (home to hub) in the frequency range of 5 MHz to 30 MHz. As mentioned previously, some cable systems are being constructed with two such cables.

It is the outside plant portion of the cable system with which this paper is primarily concerned. The efficiency of this plant is related to the installed cost and the maintenance costs. In typical urban residential areas currently under construction, there are about 100 homes per mile of cable plant, and about 20% of the cable will require construction underground. Installed costs in 1982 dollars for such plant were about $12,000 per mile for aerial plant, and $20,000 per mile for underground plant. Thus, the average plant cost for each home passed by the cable was about $140. This includes full activation of the plant for two-way carriage of signals (about $1,000 per mile) and equipping the plant with standby power for the amplifiers. Maintenance costs for such plant are in the range of $5 per home passed per year.

The two-way capabilities of CATV plant have received relatively minor usage. The primary applications to date have been for impulse pay-per-view on the "Qube" system developed by Warner/Pioneer, and for residential security alarm monitoring with technology developed by TOCOM, Inc. and others.

Although the details differ, both of these applications are similar in that communications over the cable network is done using a polling protocol. That is, data messages are sent downstream (frequency multiplexed with all the other signals) addressed to individual home terminal units by a computer interfaced to the cable plant, and a data response is sent upstream by the terminal unit indicating its status. Although polling protocols are relatively inefficient in utilizing channel capacity, for these applications and the bandwidths available the efficiencies achieved are satisfactory.

One of the factors motivating the use of polling protocols has been a fear that noise on the upstream frequencies would be severe because the noise on each branch (or split) of the network will be additive in the upstream direction. The approach to dealing with this characteristic of tree-and-branch networks has been to activate only a single upstream path through the tree at a time using what is called a bridger switch. These are switches placed in the upstream inputs of each bridger amplifier which allow the signals from only one input to be applied to the upstream amplifier. The closure of these switches can be synchronized with the polling of terminal units, thereby limiting the upstream noise while maintaining continuity. Unless these switches are made frequency sensitive (switchable filters) all usage of upstream frequencies would have to be synchronized to the polling rate, a severe restriction.

PACKET SWITCHING ON A CATV NETWORK

Current activity in the development of two-way interactive services is primarily focused on the area of videotext. Cox Cable Communications has developed a cable-based videotext system called INDAX (2, 3) short for INteractive DAta eXchange. This system is a packet switched data communications system, adapted for the CATV medium to implement the control and delivery of a combination of video, teletext, and transaction videotext services.

Two-way communication uses a multiple access protocol called CSMA/CD. Forty data channels, each 300 KHz wide, are used in each direction. Data is transmitted at a rate of 28 KB. Home terminal units provide the functions of a normal converter for delivery and control of video entertainment, and implement the functions of data transmission and reception, and display of this data in the form of graphics and text on the customer's TV set. The data modems are frequency agile, and can tune over the entire forty data channels. Traffic modeling indicates that INDAX could satisfy the videotext demands of a typical 125,000 home city using only three to six data channels.

Field operation has verified that a CATV network provides an excellent medium for packet switched data communication. The Bit Error Rate (BER) of data is directly related to the modulation technique used and to the carrier-to-noise ratio (C/N) at the receiver input. In the CATV environment, the FCC requires that the video signal measured across a 4 MHz bandwidth shall not be less than 38 dB C/N. Each INDAX data channel occupies a 300 KHz bandwidth, giving a 13 dB C/N improvement over the 4 MHz video C/N. Experiments indicate a 10^{-8} Bit Error Rate (BER) with a C/N of 20 dB. In order to meet FAA signal requirements, INDAX signals are carried 16 to 20 dB below normal video signal levels, leaving more than 10 dB headroom. The upstream C/N ratio is much more difficult to project because of the tree configuration creating the noise funneling effect previously discussed. It has been found that upstream signals should be carried at a level approximately equal to that of the return video level. Field measurements indicate that the C/N of an upstream plant with 200 miles of active cable is approximately 45 dB. Bridger switching has been found to be necessary only to isolate a branch in the event of catastrophic ingress. In such a case the bridger switch would be opened only for the leaky branch so service could be continued to all other subscribers.

SWITCHED VOICE ON A CATV NETWORK

The most straightforward way to provide switched voice (plain old telephone service) on a CATV network would be to dedicate an upstream/downstream voice channel pair for each service unit. Assuming 5 KHz voice signals and amplitude modulation, a 20 KHz voice channel should provide adequate channel isolation. A single 400 MHz coaxial cable configured so that equal bandwidth is available in each direction would provide about 8500 voice circuits. Since the maximum number of homes passed by a single trunk run is about 8000, residential switched voice capability could conceivably be provided with a single cable network for an installed outside plant cost of about $140 per service unit.

Current telephone systems take advantage of the fact that individual telephone lines are used only for a small fraction of time in any given time interval to reduce the cost of switching by equipping the switches to be able to connect only a fraction of the lines at any instant of time. These same usage patterns can be used to reduce the bandwidth required to deliver switched voice on a coaxial cable network.

Residential telephone systems are engineered to be able to handle a load of 3 CCS per line in the peak busy hour (CCS means "hundred call-seconds"). That is, on the average, each line will be busy for 300 seconds during this peak hour. A CATV trunk serving the maximum of 8000 units must then carry a worst case load of 8000 x 3 CSS = 24,000 CCS per hour, or 24,000/3600 = 6.67 CCS per second. This would be the load if all calls were evenly distributed over the hour. To account for the fact that instantaneous peaks in the load can occur, it is common, as a rule of thumb, to multiply by two to find the peak instantaneous load. Thus, the maximum number of voice circuits required to serve the load of 8000 service units is 2 x 6.67 x 100 = 1334 circuits. At 20 KHz of bandwidth per circuit, about 27 MHz of bandwidth in each direction of each CATV trunk would suffice. This bandwidth is less than the equivalent of five NTSC video channels in each direction.

Implied in this approach to delivering switched voice service over a CATV network is that electronic telephone sets having frequency agile modems are used. One would expect that the signaling required to establish connections would be done on a separate signaling channel, perhaps using a CSMA/CD protocol. The connection would be established by assigning each telephone set to an upstream/downstream voice channel pair. Inter-trunk or inter-hub switching would be accomplished by frequency translation between cables. To the author's knowledge such switching and modem technology for this approach to switched voice does not exist. However, the technology developed for the INDAX packet switched network is very similar, indicating that such technology could be feasible. The technology of cellular radio is also very similar in concept to that proposed here, again indicating feasibility.

Since bandwidth is relatively plentiful on a coaxial cable medium, it may be interesting to carry digital rather than analog voice as the overall system cost may be less. Using a form of DPCM at perhaps 32 KB, digital voice channels should fit quite comfortably into 60 KHz. In this case, three times the bandwidth, or 81 MHz in each direction, would be required for an end-to-end digital service. It may also be interesting to explore the use of a few high speed digital voice channels in conjunction with a TDMA protocol as a yet more optimal system design.

Privacy of communications can be an issue in a tree-and-branch system since the signals are available to every service unit. The opportunities for monitoring all communications, are, therefore, greater than in a conventional telephone system. Such privacy concerns are as important for data communications as they are for voice. Privacy is relatively easy to ensure for signals in the digital domain using various encryption approaches. Digitized voice, would of course, be amenable to such techniques. If conserving bandwidth were an issue for voice communications an approach in which voice is digitized, encrypted, and then converted back to analog for transmission could be considered.

OPTICAL FIBER ALTERNATIVES

Optical fiber does not lend itself to use with a tree-and-branch topology because of the difficulty of splitting and tapping signals. It is more appropriate for use in a "star" topology, in which a fiber would be run between each service unit and a central switching point. This star topology is employed in current telephone systems in the local loop plant.

In a star telecommunications system, each service unit has the bandwidth available on a loop (copper twisted pair or optical fiber) dedicated to it. As discussed earlier, this loop is idle much of the time. As a benchmark of comparison, the tree-and-branch CATV system in Omaha uses about 1200 miles of coaxial cable to pass all 125,000 homes. Four hubs are required. A star approach to wiring this city would require over 82,000 miles of optical fiber (assuming bidirectional communication on a single fiber) if fourteen hubs (switching points) are used to keep the loop length to a maximum of 2 Km.

Outside plant costs for star systems using copper twisted pairs are well known, averaging about $400 per service unit. Local loop optical fiber networks are not in commercial operation, so only estimates can be made of their costs. Indications are that an optical fiber star local loop network would not be less expensive in installed costs, at least through 1990 (4, 5, 6), than current copper twisted pairs.

Most of the current work on approaches to using fiber optics in the local loop seem to involve a hybrid topology which uses long runs of multiplexed signals from central switching centers to remote switches located within a few thousand feet of service units. Dedicated fiber pairs are then used from the remote switches to service units. The most aggressive estimate known to this author of future installed outside plant cost for such an optical fiber hybrid is $350 per service unit (6). The major cost justification for such a system is proposed to be in reduced annual maintenance costs. Such costs are estimated to be some 50% (6) to 80% (5) lower for optical fiber than copper twisted pairs. Current copper twisted pair maintenance costs are about $100 per service unit per year (6).

An optical fiber local loop network using a pure star topology would have sufficient bandwidth from the service unit to central hub to offer all contemplated services, including real time video-on-demand and real time switched point-to-point video. Certainly all broadcast type video and audio services, as well as switched and dedicated data services could be supported. However, a hybrid optical fiber network would be capable of supporting only limited video-on-demand and point-to-point video services because of the bandwidth limitations of the multiplexed run from the central hub to the remote switches.

CONCLUSIONS

Optical fiber integrated wideband local loop networks appear to have future outside plant installed costs of about $350 per service unit with annual maintenance costs of about $50 per service unit. Such networks could deliver all wideband services; except video-on-demand and switched point-to-point video services would be limited to relatively low usage levels.

A single 400 MHz coaxial cable local loop network could deliver virtually the same services as a hybrid optical fiber network. Sufficient bandwidth is available to deliver some forty channels of video entertainment programming, switched voice, switched data, and limited video-on-demand, switched point-to-point video, and dedicated channel data. Current outside plant installed costs are about $140 per service unit with annual maintenance costs of about $5 per service unit. It should be noted that equipment costs for such plant have been falling, while labor costs have been rising. Labor costs will rise independent of the medium, and on a service unit basis should bear the same relative relationship over time for the coaxial cable and optical fiber media.

Thus, coaxial cable would appear to be a significantly better investment than optical fiber for integrated wideband local loops. This is not to say that optical fiber has no useful role in a local distribution system. Indeed, it is currently a more cost-effective medium than coaxial cable for certain dedicated interconnect situations in CATV systems. One would expect that other such niches will be found for optical fibers and the future will see a blending of it with coaxial cable as the optimal solution in specific situations.

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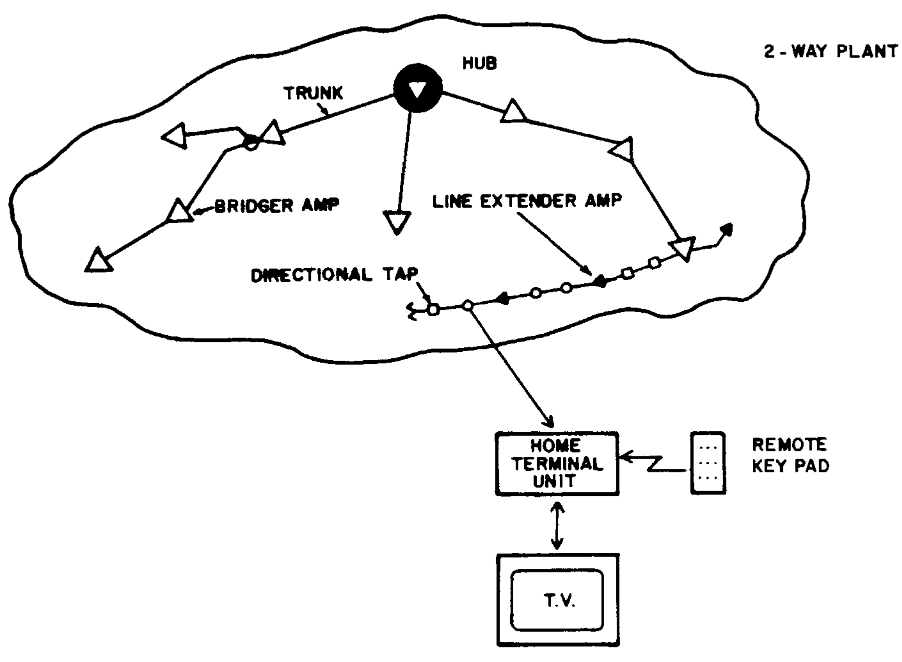

FIGURE I: CATV NETWORK FOR VIDEO ENTERTAINMENT