LOCAL DATA TRANSMISSION VIA CABLE: SYSTEM CONSIDERATIONS

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INTRODUCTION

Over the past several years, many new uses of CATV have been examined by the industry. These have tended to be oriented to private homes due to the nature of the present services being rendered. We argue here that data transmission services for the business community represent a viable opportunity.

As contrasted with new home services, the data transmission needs of businesses are well established. The uses of data transmission are known, the amount can be measured, and the demand is strong and growing.

Several new data transmission services have been introduced recently and others are on the horizon. We refer to the various special data carriers and the advent and extension of satellites and microwave. All of these are long-distance services, both high-speed and low-speed in nature.

CATV systems have at least three distinct advantages for local data distribution. First, the channels are inherently high speed. They will permit computer systems to develop along lines where communication speed is matched to computing speed, which in turn will make new uses of computers possible.

Second, the relatively fixed connection pattern of boxes in a data system is known, thus permitting the shared use of cables and limiting the need for extensive switching hardware at some central site.

Third, the CATV facilities can be shared for TV programming and data transmission channels. Thus, the incremental cost for data is low. Also, the two way retrofit of the cable plant provides the capability of handling future home services.

In this paper we discuss the technical environment of CATV and data systems, and review the relative merits of design approaches for the necessary facilities.

ENVIRONMENT

Before a data transmission business can be designed and instituted on CATV, an understanding of the technical environment is needed. This environment relates to CATV systems and data processing systems.

For CATV systems, a basic consideration is RAS: reliability, availability, and serviceability.

Reliability refers to the fidelity with which the system performs its function. For data on CATV, it may be measured in bit error rate and signal-to-noise ratio. We have run tests that indicate the bit error rate on CATV is an order of magnitude better than can be expected from other local carriers. Signal-to-noise ratio is another matter. The effect of cascaded amplifiers puts a distance limit on signals before they must be reprocessed. Electromagnetic ingress on two-way systems is a particular problem which can be alleviated by partitioning the network and digital repeating. See the discussion below under Performance Factors.

Availability refers to the proportion of time the system is actually available for use out of the total time scheduled. In a typical tree structure the effect of a failure increases in severity as it approaches the head end. Failure at the head end shuts down the entire system. For an acceptable data transmission business, such a failure needs to be prevented. Approaches to this problem are partitioning of the network (sub-hubs), alternate routing (at least for trunks), and duplexing of critical head end control equipment.

Serviceability refers to the amount of time required to repair a failed unit. Generally, a cable is quickly repaired due to its single conductor nature. For the data business, the cable operator must provide a maintenance force and spare units for customer attachments.

It is the nature of the cable that all signals exist everywhere. Hence, privacy and security are an issue. Data processing systems can provide a high degree of security for themselves with passwords and encryptions. The cable operator could provide a further degree of security by denying users access to the common cable, putting the customer attachment device on the pole and running a single line to deliver only the contracted service to the end user. Also, there is the question of the protection of the CATV network from signals of too high a level and out-of-band signals imposed on the cable by the user. The attachment device must provide safeguards.

Regarding data systems, a number of trends are important. The total number of terminals installed is growing rapidly. The distribution of terminals is somewhat bimodal. There are many single-terminal installations and many installations with a large number of terminals. The result is that most terminals appear in clusters, but the cable operator must be prepared to serve one or many.

There is a tendency to distribute intelligence in data systems. This brings compute power closer to the user and results in higher availability to the user. This trend results in interactive transactions taking place in-plant or over short distances, and batch type transactions over longer distances.

A new trend is toward networking. This means allowing any user at his terminal to have access to any application in any computer in the network within procedural limitations. Therefore, the ability to reconfigure and change the patterns of connectivity will be important.

A characteristic of data systems is their variability. Terminals are attached in stars, loops, and multipoint. Different code structures and transmission protocols are used. Data systems have built-in procedures to handle errors, to recover from failures, to time out devices in checking their operation, and to check message sequences to insure none are lost. It is most important that the CATV system not affect any of these or impose a new burden or protocol of its own.

Lastly, although a CATV system is local in nature, it must be remembered that a data system may not be. Interconnection to other carriers will have to be provided.

IMPLEMENTATION

Any discussion of transmission over a shared facility soon gets to a comparison of Frequency Division Multiplexing (FDM) vs. Time Division Multiplexing (TDM). In FDM a separate channel is given to each user. In TDM a high-speed channel is shared among many users and specific time slots are assigned to individual users. Of course, even with a TDM approach on CATV, the TDM channel is obtained by frequency division of the total cable bandwidth.

Within the categories of FDM and TDM, a further distinction is made: Fixed Assignment (FA), and Dynamic Assignment (DA). In FA a rigid designation of frequency in FDM or time slots in TDM is made to users independent of traffic. In DA a control mechanism is used to determine service needs and assignments are made on a demand basis dependent on traffic.

In the discussions that follow, we contrast FDM FA with TDM DA. These two systems provide for crisp distinction and represent the most probable approaches for implementation. One further word on TDM. Multiplexing can occur on the bit, byte, or message level. Due to considerations of synchronization and delays for turning carriers on and off, we assume TDM will occur at the message level.

Generally, for CATV, we conclude that where there is an abundance of bandwidth relative to demand and where distances are relatively short, FDM FA is better. This implies CATV in cities of relatively small size. The advantage of FDM FA is low initial cost, with cost rising in direct proportion to sales and installation. The disadvantage of FDM FA is poorer utilization of bandwidth due to interchannel guardbands and the dedication of bandwidth independent of traffic.

Conversely, TDM DA is better where bandwidth is scarce such as in large cities. The advantages of TDM DA are high utilization of bandwidth by dynamic assignment in relation to actual instantaneous traffic and the use of digital repeating to extend distance and circumvent noise. The disadvantages are the hardware and software overhead required in control of bandwidth assignment and the need for an initial expenditure for a control system when the first installation is made.

In our example of FDM FA systems, one TV channel is divided into many smaller channels. These channels are assigned to data systems on a permanent basis. Once the assignment is made between 2 (or more) units, information can be passed over the channel without further head-end involvement.

The equipment involved in FDM systems is minimal. At the user attachment point, there is an interface unit which connects through a standard digital interface. The incoming and outgoing data streams are signal converted in the RF spectrum and passed between the cable and the interface unit. The data rate on the channel matches the user device data rate.

In a TDM system, a TV channel is operated with a high data rate and is shared by all users. Time slots are assigned to users in proportion to the data rate required by the using device, and dynamically on the basis of traffic. Certain time slots are system privileged and are used for an order wire function to communicate service needs and to assign time slots. Once the assignment is made between 2 (or more) units, information can be passed without further head-end involvement. Switched line and private line service operate in substantially the same way. A variation of this scheme is to pass data through the head-end in a message store-and-forward operation.

The equipment needed for TDM systems is more involved than for FDM. At the user end signal conversion of digital data into the RF spectrum is needed. Also, digital logic is needed for system control. Since the attachment device operates at the CATV channel speed, which is much higher than the attached device speed, buffering of data is required. Lastly, head-end signal conversion equipment is needed.

The relative merits of FDM FA vs. TDM DA are discussed below grouped under system factors, performance factors, service factors and cost factors.

System Factors

Bandwidth utilization is measured in terms of how much data is being handled by a channel relative to its raw capacity. A number of factors favor TDM DA.

The same modulation techniques can be used in either TDM or FDM. Hence, the same number of bits per Hertz is possible over the bandwidth used. In FDM, however, many more guard bands are necessary between the relatively finely divided frequency slices than for the wider band TDM channels. Balanced against this is the need for system control time slots in TDM. We find for practical situations, TDM offers some advantage over FDM.

In addition, in FDM FA the channels are dedicated regardless of the presence of traffic. Line utilization of data systems is usually low. Therefore, a TDM system which dynamically assigns time slots on the basis of traffic, has an additional significant advantage over FDM FA.

Lastly, TDM lends itself to a wider range of user data rates. Time slots can be assigned in exact proportion to the net rate desired. In FDM, channels of relatively few different bandwidths are practical.

The signals in both TDM and FDM are affected by system noise and degradation through the cable amplifiers. Noise is a particular problem in 2-way CATV systems, since all attachments that enter information signals also introduce noise.

Digital repeating is a means for rejecting in-band noise and reconstituting the digital signal. In TDM systems, digital repeaters are practical, since only one is needed for the entire TDM channel at any system point. In FDM a separate repeater is needed for each FDM channel.

Digital repeaters would be placed at whatever points noise and signal degradation have reached unacceptable levels. Almost certainly a repeater would be used at the head-end. A message store-and-forward TDM system would, by its nature, provide the repeater function at the head-end.

FDM FA systems have the feature of being able to carry both analog and digital signals. This means FDM channels can carry audio and touch tone signals, as well as data. (Video, we believe, will continue to be carried at the major FDM channelizing level.) TDM DA can handle these signals, but only after converting them to digital form.

Performance Factors

Data system performance is measured by 3 major parameters: capacity, response, and throughput. Using message transmission as an example, capacity is the instantaneous data rate. Response is the amount of time from the end of a request for a message until reception begins, and throughput is the total number of messages handled over a given time interval.

Data systems use three general attachment configurations between computer sites and terminal sites to achieve desired performance: star, multipoint, and loop. In a star there is a separate computer connection and communication channel for each terminal. Terminal performance is highest with a star at the expense of multiple connections and channels.

Where lower performance is acceptable, multipoint or loop is used. In both, a single connection at the computer and a single channel exists. In multipoint, individual invitations to send data are transmitted from the computer to specific terminals. Unless a hub-polling scheme is employed, each terminal must respond, if only negatively, to assure the channel is clear for the next invitation. The capacity of individual terminals is not affected by multipoint, but response and throughput may be affected by the activity at other terminals.

In most data systems, most responses from terminals are negative. Therefore, the computer may be called upon to handle a large amount of null data. Loops are used to avoid this. In loops a general invitation to respond, sent from the computer, is examined and passed on sequentially by each terminal in turn. Any terminal with a positive response seizes an available frame. This frame is then denied to all following terminals. In this manner, only positive responses reach the computer. However, should any terminal fail, the loop is broken and all service ends. Therefore, in loops an additional level of control is needed to bridge around failed terminals.

In our TDM example, multiplexing is done at the message level. An entire message is put into the attachment device before being transmitted. This introduces a delay, which affects the response and possibly the throughput performance of the using data systems. This is certainly true for star-connected terminals and for loop-connected terminals. In the latter case the delay is compounded by the need for each terminal to handle every message. For multi-point connections, the response is affected but the throughput at the computer end can be improved over that using present carrier facilities. This is possible by providing a higher data rate service at the computer attachment than the limited rate of the terminals.

In any demand assignment system, some delay exists. Some time is needed for scanning to determine service needs and the assigning of time slots. Proper design of the system can limit the delay to acceptable levels so that user response requirements can be met.

The bit error rate attributable to the CATV medium is comparable for FDM and TDM. However, the apparent error rate as viewed by the using data system can be improved by a TDM DA service. This is possible since messages are buffered by the interface units (due to the difference in data rates between the cable and the data device). Transmission can be checked for errors and retries made by the communication system. The existence of a transmission error, in this case, affects response and throughput momentarily. But the data system is saved from invoking its own error recovery procedure, which would involve a retry plus control program execution time.

A second side of the performance issue involves the network itself. In any shared system such as TDM DA, there is a finite probability that the facilities will not be able to respond to a service demand. Proper system design and loading can keep the occurrence of "system busy" incidents low. System control can be structured to provide levels of service ranging from dedicated to a dial-up equivalent to assure performance at the user level commensurate with need (and cost). A property of a TDM DA system is that its control mechanism is constantly scanning and examining all its system elements. The primary purpose of the scan is to locate those users needing service. Given this property, however, it becomes easy to add new features. The system can locate failing attachment devices. It can identify faulty lines and institute alternate routes. In short, the system can monitor its own performance and take actions necessary to remedy failures.

Service Factors

The communication services available in an FDM FA system are essentially those presently available from existing carriers. Dedicated frequency bands substitute for hard wire channels. Proper selection and use of these new frequency channels will accommodate star, multi-point, and loop terminal operations. Also, the frequency bands can be provided in a variety of bandwidths to match popular data rates.

TDM DA can match these same services. However, new communication services become possible. A private line service with billing based on actual usage can be offered. A wider range of data rates is possible. Various levels of service priority can be offered and charged for accordingly. The TDM DA system can be instructed to alter the using data system connectivity paths so that the using data system can be reconfigured. This alteration can take place on a scheduled or on a demand basis.

Finally, the using data system cost/performance can be enhanced by the transmission error checking and retry of the TDM DA system, and having a higher data rate service at the computer attachment as described above.

The usefulness of CATV for data transmission would be greatly enhanced through interconnection to other media and carriers. These include telephone companies using switched, private line, T1, and DDS services, satellites, microwave, etc.

Interconnection can be viewed from the standpoint of the user or of the cable operator. The user can achieve his own interconnection by using separate attachment ports on his equipment. Where the cable operator provides interconnection, it is most likely to be on a bulk basis shared over multiple users. With an FDM FA system, some signal processing is probably unavoidable to make the frequency bands contiguous. The problem of S/N degradation limits the amount of interconnection and the distances involved. Digital repeating can be done, but has the problem of multiple and separate channels. It may be possible to treat a group of channels as a single signal and perform an analog-to-digital conversion. These approaches, however, add cost to the interconnection equipment.

Cost Factors

The equipment cost in a CATV data transmission system is divided into three main categories: the attachment device, the communication channel, and system control.

Attachment device cost is directly related to function. TDM DA and FDM FA have similar functions in signal conversion and RF (radio frequency) modulation and demodulation. TDM DA has additional function in buffering and logic for system control.

Channel costs relate to the bandwidth used, equipment added to the cable plant to permit transmission, and in the case of TDM DA, the amount of time the channel is occupied by a user. Since typical data systems have relatively low channel utilization, we find that substantially more users can share a TDM DA channel than can share the same bandwidth in FDM FA and the cost per user is less.

System control cost relates to that part of the system that handles the dynamic assignment of bandwidth. This cost is imposed when the TDM DA system is installed. It can be a major item relative to other equipment cost for the first customer. However, it quickly reduces on a pro-rata basis as customers are added so that it is only a few percent for a fully loaded system.

The attachment device will cost more for TDM DA. Recently there have been a number of developments in digitally controlled frequency synthesizers capable of RF. These devices are attractive for FDM attachments. A single type number box can be used for all frequency assignments. This eases maintenance and system management. Any box can be used at any point and its assigned frequency programmed into it. Frequency assignments can be altered to reoptimize the cable system and permit system testing.

Conclusions

Based on our studies we conclude data transmission can be accomplished on CATV. Further, as pointed out above, CATV has some unique advantages over present facilities.

From an implementation viewpoint, FDM FA seems a low cost way to enter the business and probably satisfies the small city case. TDM DA offers significant system advantages and better satisfies the large city case.

Finally, we note the great diversity in data systems -- codes, line protocols, logical attachment modes, procedures, system programming, and data equipment. Behind these lies a great industry investment. To be successful, cable systems, providing communication links, must not impose unique modifications or requirements.