Fiber optic distribution systems

By T.J.B. Swanenburg

In recent years, enormous progress has been made toward the introduction of fiber-based customer access networks, which allow for easy access to a large variety of services. In many countries, pilot projects are in operation or in an advanced planning stage. All these projects offer a multitude of existing or new services to the customer, often at a better quality than the existing telephone or cable television networks.

The standardization by CCITT of the Synchronous Digital Hierarchy,[1] originally proposed by Bellcore under the name SONET (Synchronous Optical Network), opens the way to standard digital access equipment, operating at 155 Mb/s or 622 Mb/s. There is little doubt that in the near future broadband digital access based on fiber optic transmission will be installed on a large scale worldwide for business customers. This paper discusses the hurdles that have to be overcome to make "fiber to the residential customer" a viable option.

Broadband networks

During the early 1980s, the first ideas about Broadband Integrated Services Digital Networks (BISDN) emerged in the wake of the worldwide acceptance of Narrowband ISDN (144 kb/s). The practically unlimited transmission capacity of optical fiber was expected to reduce the cost of communication by orders of magnitude. Everywhere, telecommunication operators adapted their planning in response to the advent of the fiber.

Indeed, today all new long distance, inter-exchange, and feeder connections in the telephone network are fiber based and many existing transmission systems have been upgraded to fiber. For these parts of the network, the advantages of the introduction of optical transmission are evident: the transmission capacity per system is much larger than for coaxial systems and the low attenuation of the fiber allows for an enormous reduction in the number of repeaters, thus making the network more reliable and less costly to maintain.

The construction of an all-digital integrated network, which would give customers easy access to all existing, as well as many new services, seemed to be just around the corner. However, under the influence of a strong technology push, one problem had been overlooked. The cheap transmission facilities offered by fiber optic systems can only be realized if a large fraction of the system capacity is used. This will certainly be the case in the higher layers of the telephone network, but not for the residential customer who is making a phone call or has his PC connected to the network.

The only existing service that will need the available bandwidth is the distribution of television. However, this service is provided already in many areas by relatively cheap coaxial CATV systems. This is the dilemma to be addressed: fiber optic customer access networks need to transport TV to be economically viable, but to be competitive, cheap solutions have to be provided. Once this problem has been overcome, a large variety of new video-related services can be implemented relatively easily, thus creating a customized video communication environment.

TV distribution: The problems

The vision of a fully integrated, digital network providing all possible services (including television) to all customers was completely in tune with the properties of optical transmission systems: linearity and noise figures of semiconductor laser diodes were such that analog modulation was not an acceptable option. However, together with the decision "to go digital," the bandwidth required for the transmission of TV is increased dramatically. As an example, straightforward A/D conversion of a TV channel (which occupies a band of 6 MHz in an AM-VSB modulated system) generates a bit rate of the order of 100 Mb/s. Providing tens of TV channels to a residential customer in a time-multiplex mode leads to bit rates of a several Gb/s. Each customer will need de-multiplexing electronics operating at this speed to select a desired channel.

Today, the performance of semiconductor lasers has increased considerably, both with respect to noise and to linearity. Recently, both AM and FM modulated systems carrying several tens of channels have been demonstrated.[2] Although on a relatively short term these options may be attractive, we will only address digital solutions.

The challenge of a digital, integrated system remains. It should be possible to find economically viable ways for using the bandwidth of many thousands of GHz provided by the optical fiber,

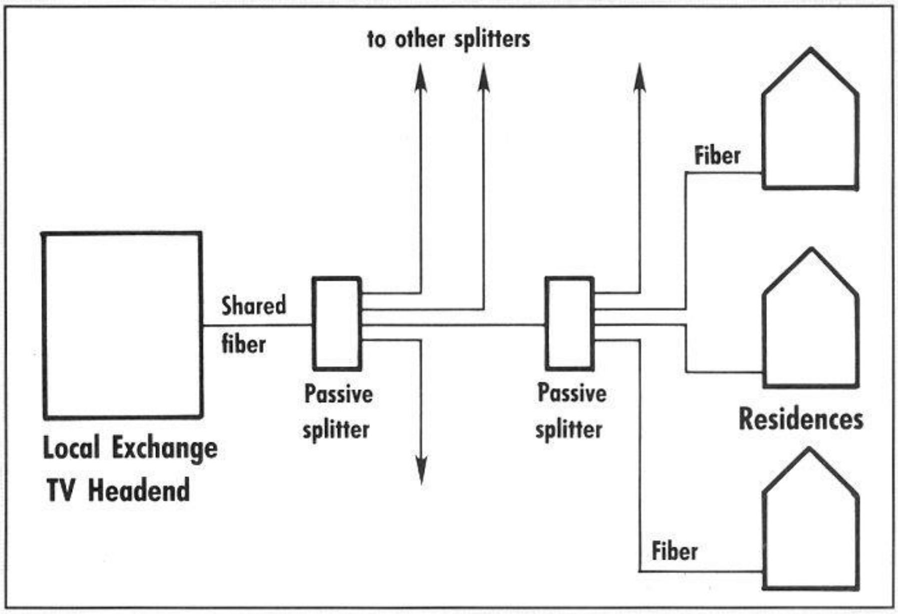

FIGURE 1. Resources are shared, same information is transmitted to all customers.

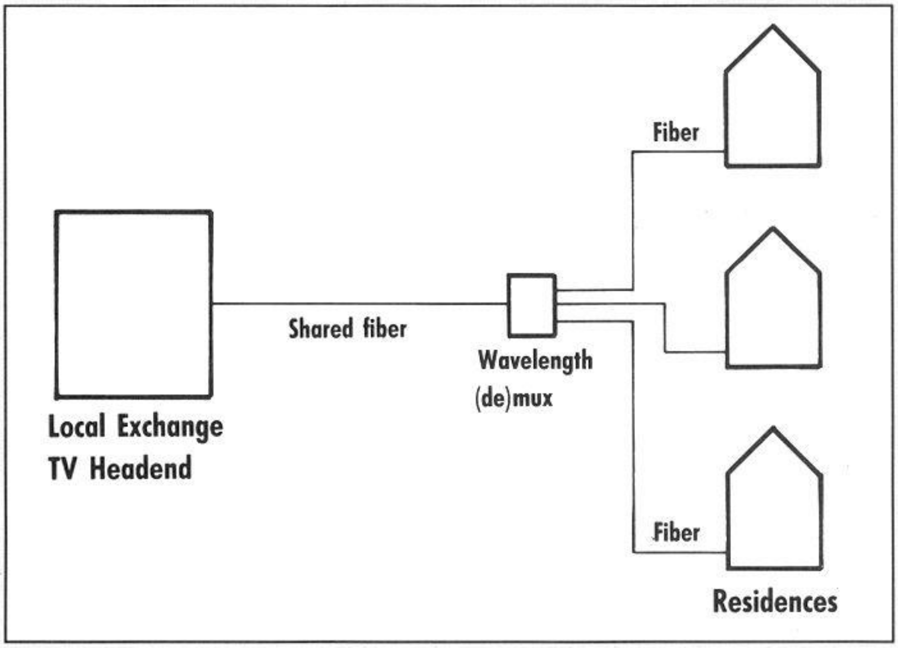

FIGURE 2. Resources are shared, but each customer has his own wavelength.

and at the same time exploit the inherent advantages of digital transmission and signal processing.

TV distribution: The options

It should be realized that the problems that originate from the digitization and multiplexing of a large number of TV channels are essentially problems in the domain of electronics: it is not trivial to handle several Gb/s in a residential environment. Basically, there are three independent ways to overcome this electronic bottleneck:

- source coding the digitized TV channels may considerably reduce the bit rate per channel, and thus diminish the total transmission rate;
- selecting those channels a particular customer wants to watch out of a multitude of channels available in the local switch; or
- using a large number of wavelengths in the optical domain, so as to reduce the bit rate per wavelength.

Evidently, combinations of these three possible measures are feasible too, but for reasons of clarity, we will discuss the various pros and cons separately.

A lot of work is being carried out worldwide in the domain of video source coding for services ranging from videotelephony and videoconferencing to TV distribution. The requirements in terms of picture quality are very different, and so are the related bit rates; for videotelephony, 384 kb/s or even 64 kb/s seems to be acceptable and normal television can be compressed to less than 10 Mb/s. However, the relevant question is not only whether it is technically feasible to compress by a certain factor, but also what the related costs are. In particular, the price of decoding (which has to take place at every subscriber or even in each TV set) is of utmost importance.

The option of selecting only those channels required by the subscriber is a viable one. The number of channels to be watched or stored by one subscriber at a particular moment is limited to three or four, so there is no need to "dump" all available channels to all customers. Apart from possible obstacles in the sphere of privacy, this solution has numerous consequences for the network as a whole. First of all, the question has to be answered whether the selection or switching function is an integral part of the broadband switch. If the answer is negative (which implies that a separate broadband selector is used for selecting the TV channels), the dream of a fully integrated network is violated. Integration takes place only at the level of multiplexing and transmission. If the answer is positive, completely new requirements for the switching and call set-up functions emerge: all customers will switch to the "eight o'clock news" at the same time, and they are used to an immediate response.

The third option essentially is an optical analogon of radio broadcast systems. Instead of RF carriers, now optical carriers at different wavelengths (or frequencies) are employed to transmit different information channels. The first advantage is that the information (bit rate) per carrier can be maintained at a level that can be handled easily and cheaply electronically. Second, if optical heterodyne or homodyne techniques are applied, the number of channels is practically unlimited.[3,4,5] However, the problems have now been shifted to the optical domain. Wavelength or frequency multiplexing of optical carriers requires light sources with a spectral purity and stability that is not too easy to obtain. The wavelength demultiplexing function that has to be performed at the subscriber's premises to select the required channels is not trivial either. Nevertheless, both high-density wavelength division multiplexing (HDWDM) and coherent multi-channel (CMC) systems receive a lot of attention today.

TV distribution: The networks

In the past, most experiments and pilot projects were based on the assumption that the network topology for future BISDN networks would be very similar to that of the present telephone network, *i.e.*, a full star configuration with one individual fiber per customer. For residential customers, however, the enormous transmission capacity of that fiber would be used mainly for TV distribution, a service which nearly by definition asks for sharing of resources. Therefore, several other approaches have emerged over the past few years in which fiber or bandwidth sharing is exploited and the cost per subscriber is lower.

Before embarking on a more detailed discussion of the various network architectures, it is necessary to be aware that the most expensive part of any fixed telecommunication network is the cable infrastructure. That means that installation of fiber cables, in particular in the local network, is crucial in the sense that mistakes or erroneous estimates about future use cannot be corrected easily. To accommodate growth in demand for capacity, an evolutionary strategy has to be adopted that allows for simple upgrading of the cable infrastructure.

The familiar full-star network can accommodate, in principle, all possible solutions for distribution of TV. Because of the short distance (2 km on the average), the power budget is not critical and more than enough bandwidth is available. Almost any increase in demand can be met by an exchange of the opto-electronic equipment. It is the most future-proof, but also the most expensive, architecture.

Several institutes have suggested architectures in which (part of) the fiber is shared by many customer's. Typical examples are the Passive Optical Network (PON) proposed by British Telecom[6] and the tapped fiber architecture by Raynet Corp.[7] In a PON, one fiber from the local exchange is connected to two or three successive passive optical splitters that distribute the optical power over typically 32 customers. Such a network has the advantage that the transmission equipment in the exchange and a part of the cable are shared by all customers (Figure 1). Basically, the PON architecture is well suited for distribution services, because all transmitted information is received by all customers. For dialogue services like telephone, time division multiple access (TDMA) protocols are required.

A slightly different version of the PON architecture[8] has recently been investigated by Bellcore (Figure 2). Each customer is served by a different wavelength and a passive wavelength (de)multiplexer takes care of combining all traffic onto a shared fiber connection to the exchange.

Finally, in the Raynet system, a tapped fiber topology is applied. Multiple taps on a (shared) fiber backbone deliver the standard broadcast television signals (in AM-VSB format) to fiber distribution cables (Figure 3). The last drop is coaxial cable. In this system, the main limitations originate from the use of AM-VSB signals. For transmission in digital format, it would be quite analogous to the various PON architectures.

Looking ahead

We have tried to outline the main issues that are pertinent to fiber-optic distribution networks. At present, it is too early to predict which topology or which transmission or coding formats are going to win. Although in a purely technical sense fiber optic technology is relatively mature, assessment of exact costs for the customer access connection is difficult, and choosing the solution which is the cheapest today may turn out to be a bad investment tomorrow.

The advent of optical amplifiers, which have attracted a lot of attention recently,[9] may change present tradeoffs completely. The power budget, which is a problem today in tree-and-branch networks both for analog and for digital systems, may no longer be an obstacle.

Therefore, we feel that more research, but in particular also pilot experiments, will be required to arrive at solutions that are not only economically viable today, but also allow for a graceful evolution in future.

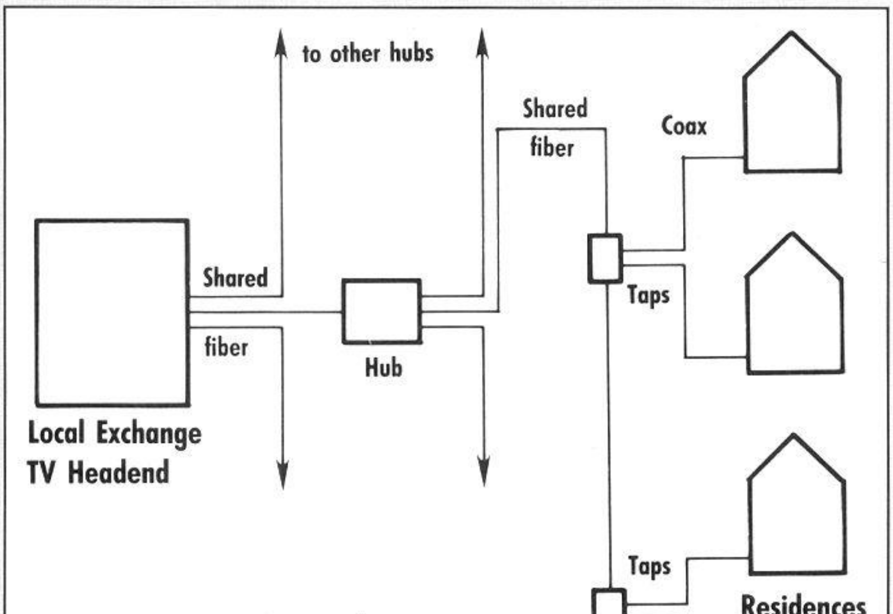

FIGURE 3. Tapped Fiber Network

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