An Engineering and Policy Analysis of Fiber Introduction into the Residential Subscriber Loop

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***Abstract*—This paper presents an engineering cost model which provides a framework for evaluating alternative network architectures for providing fiber to the home. The analysis employs this model to construct estimates of the average cost per subscriber of several network alternatives which have been proposed in the literature. Our results identify two possible network architectures, the active double star and passive double star, as particularly attractive alternatives. Sensitivity analyses provide detail on the critical contributors to overall costs. The paper concludes with a discussion of several policy issues raised by the analysis, including issues of the proper allocation of risk from fiber-to-the-home investments.**

I. INTRODUCTION

RAPID advances in fiber optic technology over the past 10 years have resulted in numerous proposals to develop broad-band fiber optic networks that would reach every household and provide the infrastructure for a vast range of new services. Before such a vision can be realized, however, numerous technical, economic, marketing, and political barriers must be overcome. This paper presents a preliminary analysis of the engineering, economic, and policy aspects of wiring the nation's residences with fiber optics. The study simulates geographical areas where the existing copper wire telephone plant in the local loop is *rehabilitated* by fiber optic connections to every network subscriber. Engineering cost models have been constructed to simulate the deployment of a fiber optic residential subscriber network. The approach focuses on the costs of a fiber optic residential subscriber network (FORSN) from the central office (CO) of the telephone company out to the subscriber's premises. The models assume medium term (5–10 years in the future) technology options in order to examine the economic implications of alternative optical network architectures. In addition, the analysis considers some policy issues which are raised by the results of the models.

II. FIBER OPTIC RESIDENTIAL SUBSCRIBER NETWORK ALTERNATIVES

The key decisions in any architecture are where to put switching and multiplexing functions, and how to share transmission resources. This study examines three FORSN designs common to the literature: the switched star, active double star, and passive double star. For each alternative an engineering planning model determines the cost of installation over one quadrant of a network (Fig. 1). This section reviews these architectures and examines the component technologies whose cost and performance characteristics ultimately determine the feasibility of an overall architecture.

A. Switched Star

Star networks, similar to the existing voice network, dedicate individual fiber pairs from the CO to each subscriber. All switching occurs at the CO to take advantage of any economies of scale. The principal disadvantage is the amount of fiber required. This architecture is preferred when the cost of switching is high relative to the cost of transmission capacity.

The model assumes that the CO provides up to four STS-3 (155.52 Mbit/s) video channels to each subscriber.[1] A single fiber carries the time division multiplexed (TDM) channels to each subscriber along with N-ISDN traffic for voice; wavelength division multiplexing (WDM) allows the use of the same fiber for the return N-ISDN channel. At the subscriber's premises, after demultiplexing the signals, a video codec converts the digital video signals to analog modulation for a standard TV. Fig. 2 provides an example of the subscriber premises equipment.

B. Active Double Star

The amount of fiber in the feeder plant can be reduced, relative to the switched star, by deploying *active* switching units in remote distribution units (RDU) that allow for pair gain over the feeder fiber. The CO configuration for an active double star network is shown in Fig. 3. Video signals (STS-3) and N-ISDN signals (144 kbit/s) arrive

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Manuscript received February 17, 1989; revised June 8, 1989. This work was supported in part by a Grant from Bell of Pennsylvania.

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IEEE Log Number 8930494.

[1] All the models assume a synchronous optical network (SONET) transmission hierarchy at the physical layer. In part, SONET describes a family of synchronous transport signals (STS), designated as STS-M for electrical signals supporting M signals at the DS3 level. The optical carrier (OC) counterpart is represented as an OC-M signal [3]. The CCITT has agreed upon standard broad-band interfaces at multiples of 51.84 Mbit/s. Thus, STS-1 and STS-3 rates correspond to 51.84 and 155.52 Mbit/s, respectively.

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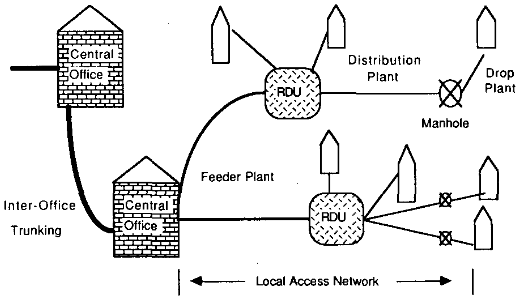

Fig. 1. Telephone system local subscriber loop plant.

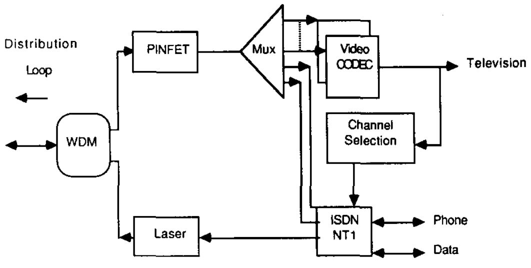

Fig. 2. Subscriber's premises equipment.

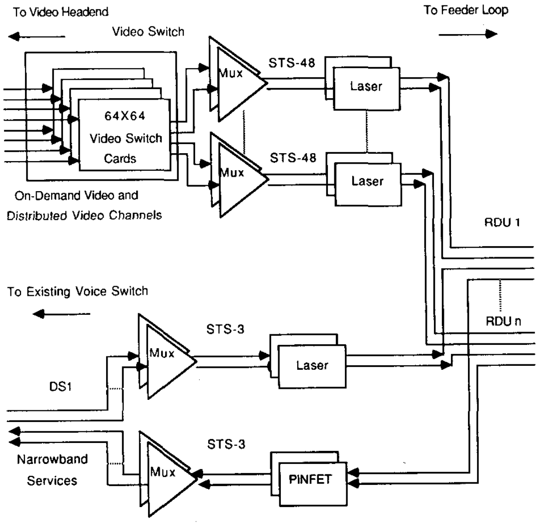

Fig. 3. Central office configuration.

at a CO on incoming trunks. Separate switching matrices handle each signal. Feeder fibers connect the CO to the RDU at the STS-48 rate (2.488 Gbit/s). A designated fiber carries the multiplexed N-ISDN traffic for each direction. Sufficient fibers to handle the estimated peak demand are devoted to downstream video traffic.

At the RDU, after demultiplexing the STS-48 into STS-3 signals, the video signals are fed to a switching unit based on CMOS cross points operating at the STS-3 rate. Simple demultiplexing alleviates any need for remote N-ISDN switching. Each subscriber receives over the distribution fibers up to four video outputs multiplexed together with an N-ISDN signal (Fig. 4). An upstream channel is necessary for the N-ISDN traffic. WDM between the subscriber's premises and RDU results in a single fiber per household in the distribution loop. Equipment at the subscriber's premises is the same as for the switched star.

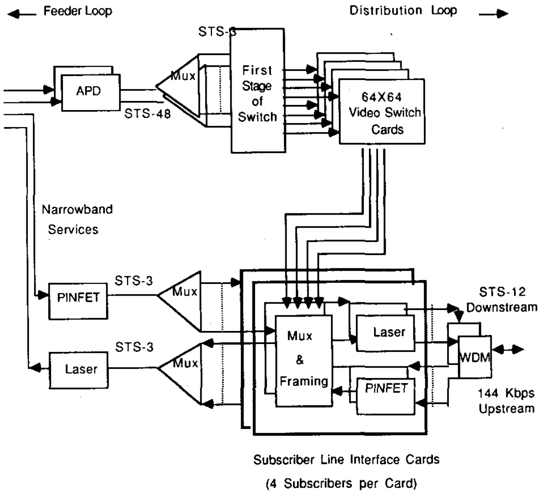

Fig. 4. RDU for active double star.

C. Passive Double Star

The light signal on a fiber can be split optically onto two or more fibers by simple passive devices. In a passive double star, multiplexors combine the signals for several households—by either TDM, WDM, or both—onto a single fiber at the CO. At the RDU a passive splitter replicates the optical signal onto individual distribution fibers. Equipment at the subscriber's premise, using directions sent from the CO, selects the correct signal from the several multiplexed on the fiber. Configuring the network as a double star rather than as a bus simplifies maintenance by locating the passive splitter at a single well defined point. Also, there is less excess signal loss from a single $1:n$ splitter than from a succession of taps on a bus, thus allowing more subscribers to be served within the available signal power. Having the signals of several subscribers come into each household, however, raises the issue of securing the information privacy of each subscriber.[2]

In the active double star design, the video channel rate is set at STS-3 in order to minimize the cost of video codecs. Cost considerations limit the multiplexors on the subscribers premises to STS-12 (622 Mbit/s). At these rates the passive double star could provide only four dis-

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[2] Oakely *et al.* [21] argue that security represents an attribute of the passive star system and not a weakness. The reasoning is that tapping an electronic or optical bus signal with its complicated frame structure is much more difficult, and easily detected, than tapping a copper wire pair. With more effort and cost, the subscriber's privacy can be further protected from unwanted surveillance by additional signal coding and physical isolation of the network termination equipment.

tinct channels per fiber from the CO. Moderately more costly codecs allow reduction of the video channel rate to the STS-1 level, while keeping the TDM rate at STS-12. The STS-1 rate, while adequate for NTSC video signals, may be inadequate for EQTV or HDTV. Nevertheless, this architecture economizes substantially on fiber by comparison with a single star, while using only low cost passive equipment in the RDU. Moreover, it does not require the development of remote video switches capable of operating at 150 Mbit/s rates. This approach can be viewed as one which is more easily achievable with current technology, while potentially more limiting in terms of future demands for HDTV.[3]

D. Component and Subsystem Issues

One cannot choose readily among these architectural alternatives without examining in more detail the choices available for the component technologies and their economics. Our approach assumes widespread introduction of an FORSN in the 1995–2000 time frame. Consequently, in comparing technical options, we make some allowance for the maturing of technologies which today are only available in prototype form. At the same time, some techniques, such as coherent modulation and detection have been judged sufficiently distant technologically, that they are not considered in this analysis [26]. Also, we assume that widespread use of optical fiber for residential services will yield further reductions in cost below today's levels. As with N-ISDN circuitry, key circuit components will be implemented as single VLSI chips. Our technical and cost forecasts reflect these assumptions.

All models assume single mode fiber throughout at a price of $0.10 per meter [15]. We also examine alternative prices of 5 and 20 cents per meter. Our analysis shows that it will be cheaper to use WDM on the distribution fibers—as opposed to separate fibers in each direction—while reliability and expansion concerns suggest separate fibers in the feeder segments.

The optical power budget determines the combination of optical sources and detectors to be used in a given configuration. Throughout the study, we choose the cheapest combination of components to meet the desired power margins. Edge-emitting light emitting diodes (LED's) are chosen over laser diodes (LD's), just as p-i-n photodiodes are chosen over avalanche photodiodes (APD's) whenever the optical power levels and bandwidth requirements made the exchange possible.

A wide range of proposals have been suggested in the literature for the channelization of fiber to the home [2], [4], [12], [23]. The key tradeoff in setting the rates of the many different services to be multiplexed on the fiber lies between the capacity available, and the cost of signal processing and compression. We have chosen to consider two proposals in detail which are consistent with recent CCITT standards concerning broad-band transmission interfaces. The first option calls for an aggregate STS-12 data rate to each subscriber which is composed of four STS-3 broad-band channels [4]. The second approach calls for video channels at the STS-1 level. The lower bit rate allows for more fiber pair gain when using passive splitters.

TABLE I
COST OF OPTICAL COMPONENTS

Optical Network Subsystem Component Costs			
Component	Cost	Description	Source
Single Mode Fiber	$.10/meter	Cost of glass fiber	[15]
LED or LD (STS-12)	$50	Includes circuitry & pigtail	[6] and [17]
PINFET (STS-12)	$50	Photodiode	[6]
Laser Diode (STS-48)	$100	Includes circuitry & pigtail	
APD (STS-48)	$100	Avalanche Photodiode	[24]
64X64 Switching Card	$200[1]	STS-3 channels, assembled	
Multiplexor (STS-48)	$1200[2]	Fixed cost only	
Subscriber Line Card	$600[3]	Interface Card (4 Subs/card)	
Star Coupler	$25	Cost per port	[1]
SM Connector	$27.50[4]	Includes labor, installation	
Splice	$20	Fusion splicing	
WDM	$30	Two wavelengths	[1]
Video Codec	$40[5]	Conversion to analog signal	

[1] Bellcore has implemented a 16 × 16 cross point as a single IC of about 25 mm^2 in 2 μm technology; and a 64 × 64 switch with all drivers, receivers and control logic has been built on a single card [5]. In quantity, a CMOS chip of 25 mm^2 in 2-μm technology can be produced for under $5 today.

[2] High speed multiplexor requires GaAs IC—which are currently available, stand alone, for less than $100/chip.

[3] Price assumes four transmitter/receiver pairs, plus simple multiplexing and switching chips, on each card.

[4] Assumes single mode connector cost of $15 plus 15 minutes of labor/connector at loaded labor rate of $50/h.

[5] The video codec is the digital-to-analog converter needed for digital signals at the subscriber premises. Codec implementation would follow the design of [2] requiring four full custom chips plus additional circuitry.

In both cases, we visualize an equivalent N-ISDN basic access rate or primary rate interface being multiplexed with the video channels. This allows the use of existing N-ISDN switching capacity, rather than replacing such capacity with, for example, broad-band packet switches for both voice and data.

A widely proposed circuit-switched alternative is a space division switch with crosspoints implemented in a VLSI circuit. Several investigators [2], [5], [8], [23] have demonstrated prototype switching matrices capable of operating in the 150 Mbit/s range. It appears, therefore, that relatively inexpensive switching for STS-3 digital video channels can be realized. Recently proposed ATM switching techniques are consistent with the network architectures examined here [20]. Although our study does not explicitly consider the economics of this alternative, it does provide a benchmark against which the costs of ATM components can be compared. Of course, if ATM techniques allow for more services to be transported, hence generating a greater revenue stream, then higher electronics costs could be justified.

Several architectures call for multiplexing multiple video channels at feeder rates up to STS-48. These rates

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[3] It is possible, of course, that future development of high density WDM or coherent modulation and detection technology, will make it economical to use wavelength division multiplexing together with a passive star architecture to provide higher channel rates to each subscriber.

exceed the capabilities of CMOS technology, calling for gallium arsenide components of only medium scale integration. As a consequence, we believe such multiplexors will be considerably more costly than switching matrix components.

Table I lists our assumptions concerning the costs of the subsystem components. All of the costs for electronics and electrooptics are marked up a further 40 percent to cover installation and testing.

III. Model Assumptions

The next section presents assumptions inherent to the layout of the FORSN models, including how the models are dimensioned based on estimates of broad-band services demand. The discussion introduces a copper model serving as a baseline for comparison.

A. Layout of the Models

The FORSN models focus on the case where fiber is being overbuilt in a neighborhood already serviced by copper, since this will ultimately be the most common case. The models assume that when an existing area is rehabilitated with fiber, all existing telephony (N-ISDN) subscribers have their service moved to the new fiber plant. Thus, we assume enough fiber is installed to handle 100-percent penetration. At the same time, not all subscribers are assumed to sign up for new video services. Video switching electronics at both the CO and RDU are assumed installed only as subscribers sign up for video services.[4] If the existing copper plant is still capable of providing voice services, the cost of installing fiber should be borne strictly by those demanding the new video capabilities. Accordingly, in calculating the cost of fiber per household, we take the total incremental costs of fiber installation and related electronics, and divide by the number of subscribers to broad-band services.[5]

The serving area under study consists of 1000 households in a neighborhood laid out as a grid of square blocks with a typical density of 100 homes per street mile. The RDU lies in the center of the serving area. The distances from the CO to the subscriber are assumed randomly distributed similar to published data reporting average working loop lengths found throughout the Bell System [12], [25]. Our copper baseline model calls for large (e.g., 600 pair) cables to be laid for one or two blocks from the RDU, and then spliced onto successively smaller cables branching out at intersections. However, because splicing costs are much higher for fiber over copper, we assume multiple smaller fiber cables are run out from the RDU, eliminating the need for splicing within the distribution area. Standard cable sizes of 12 and 36 fibers each are assumed in the passive and active double star models, respectively. A protection factor specifies the percentage of dark fiber which is installed to cover either fiber failures or future growth. Installation of distribution cable includes inner duct. Splices connect the distribution cables to the drop cables, which run from manholes (spaced one or two per block) to the residence. Drop cables are without inner duct but have a rodent-proof sheath. Fiber cable installation cost is \$10 per meter.

All of the fiber models provide customers with downstream video services, and full duplex N-ISDN services. We have not considered upstream video from the home, as would be required for videotelephony.

B. Demand for Video Services

While much has been written regarding future services to the home [14], we believe the principal source of revenue to cover the cost of installing fiber will be the delivery of entertainment video. Indeed, many of the new services described in the literature can be delivered prefectly well via N-ISDN over copper loops. Only moving images require the bandwidth of fiber.

Estimating the number of subscribers who at any one time will prefer to watch distributive video versus on-demand video is critical to sizing the feeder plant and the remote switching unit in the active double star. Our model assumes that 36 channels of distributive video are automatically provided to the RDU from the CO. Requests for distributive video programs beyond these 36 channels are equivalent to on-demand video requests.

We desire to provide enough channels between the CO and the RDU so that the probability of no channel being available to service a request is below some set grade of service (GOS), typically 0.01. We assume that a request can be serviced by any available channel; however, if there are no available channels, the requestor goes away.[6]

It is necessary to estimate the offered traffic A in order to determine the number of necessary servers K given some predefined grade of service. In the absence of any commercial experience with on-demand video, we assume that VCR owners approximate the viewing habits of potential on-demand viewers in order to estimate the average offered video traffic. According to the A. C. Nielsen Co., in 1984 the average owner of a VCR will, three years after the purchase, watch 42 minutes per week of video cassettes or about 2 movies per month [7]. We have explored a range of values up to 3 hours/week.

Not all video requests will occur during the peak busy hour—only a percentage of the weekly average. The model assumes 20 percent of the weekly viewing occurs during the busy hour, e.g., 8:30 P.M.–9:30 P.M. on a

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[4] Enough feeder fibers are installed initially to handle 100-percent penetration. Depending upon the rate at which subscribers sign up, it may be cheaper, in present value terms, to defer some fiber installation, even though going back to reinforce an existing installation has higher costs than installing it all at once. (See Reed and Sirbu [27].)

[5] One could argue that a portion of the capital cost for fiber may be properly attributed to current N-ISDN service customers, a portion equal to the present value of maintenance cost savings resulting from the switch from copper to fiber. We estimate this portion to be less than \$100 per subscriber and have ignored it in our presentation of results.

[6] This is usually referred to as a full availability, loss system. For alternative models which assume that the caller retries within a short time interval see [16].

weekend night. This compares to a mere 0.59 percent if the traffic were uniformly distributed over the 168 h in a week. We must also allow for the possibility that there is more than one television in use in a household, each tuned to a different program. Hightower notes that some 15 percent of CATV subscribers have a second drop [13]. Our model assumes that second, third, and fourth drops increase the total number of users by 20 percent over the base number of households subscribed; however, these additional drops generate requests for on-demand service at half the rate of the primary drops.

As described in Section II-C, the passive double star architecture multiplexes video signals for several subscribers onto a feeder fiber from the CO. Transport of a unique channel per subscriber prohibits any opportunity for gain due to viewing statistics. Thus, if M is the number of channels per fiber, and S is the fraction of additional channels per household which will be viewed concurrently with the primary connection, then the number of households served per fiber equals $M/(1 + S)$.

C. Conventional Copper Loop Design

As a baseline for comparison, the model determines the current cost of new construction based on fiber feeders and copper distribution to the home. Single mode fiber running at the DS3 rate (45 Mbit/s) carries multiplexed voice circuits from the CO to the RDU in a logical star design. The model assumes a 1 : 1 protection ratio for the feeder fiber. At the RDU, equipment demultiplexes the DS3 down to the DS1 rate (1.5 Mbit/s) and feeds to several SLC-96 type channel banks. The RDU receives power from the local public utility, with power conditioning and 8-hour battery backup provided in the RDU [18]. Copper pairs run from the RDU to a terminal housing serving six households, and then via a drop wire to the residence. This model assumes buried construction throughout and the use of four cable sizes—600, 300, 100, and 50 pairs—which are spliced together as necessary to cover the distribution area. Much of the cost data can be found in [9].

D. Fiber Plus Coaxial Cable

A majority of households already have a coaxial cable running down their street, if not all the way to the house. Significant savings in installation costs could be realized if the existing coaxial cable drops could be used in conjunction with fiber distribution.[7] For example, the passive star architecture multiplexes 12 channels onto a single fiber. Instead of an optical splitter and fiber drops to the home, one could replace the splitter with broad-band modems which frequency multiplex the same 12 video channels onto the existing coaxial cable plant for delivery to the home. Existing copper pairs provide the N-ISDN services. The results consider a variation of the passive star architecture which assumes the use of existing coaxial cable and copper pairs for the final drop to the residence.

IV. RESULTS

Using the basic assumptions detailed above, this section reports the results of the engineering cost models in addition to a few sensitivity analyses in an attempt to better understand the economics of a FORSN.

A. Conventional Copper Loops

Our baseline copper model gives a cost of $1000 per subscriber, at today's costs, for providing outside plant for conventional telephone services. The model assumes sufficient plant is installed for 100-percent penetration and 20-percent second phone lines. Fig. 5 provides a sensitivity analysis showing the effect of different copper cable installation costs and households per street mile.

B. Active Double Star

A key question is the total capital cost per subscriber to provide new fiber-based services. When fiber replaces copper which is still capable of satisfactorily providing narrow-band services, the total costs should be attributed to those demanding broad-band service. In practice, much of the capital must be invested up front, before it is known how many residences will choose to subscribe to video services. Thus, from this perspective, the cost per subscriber depends strongly on the assumed penetration rate of video. Fig. 6 shows the average cost per subscriber as a function of the fractional penetration for various estimates of fiber cost per meter. The figure assumes 1.5 hours of video on demand viewing per subscriber per week.

Several previous studies suggest that capital costs must be in the range of $1000 to $2000 for a FORSN to be viable. These results suggest that this range can be achieved, but only if there is substantial penetration of the targeted neighborhood. Some insight can be gained by examining the relative contribution from several components of the cost. Fig. 7, calculated on the basis of 60-percent penetration, shows that the largest component by far is the distribution loop, followed by the RDU equipment costs. Active switching at the RDU dramatically reduces the need for feeder fibers, which thus contribute only a small portion to the total cost. CO costs include loop termination costs plus only those minimal investments in switching which go beyond what would be in place to supply N-ISDN service.

Distribution loop costs are sensitive to assumptions about population density. Fig. 8 shows how distribution loop costs change if the lot sizes and typical block lengths are adjusted to correspond to 75, 100, and 150 houses per street mile, while holding fiber costs at $0.10 per meter.

1. On-Demand Video: While most of the loop plant varies only with the number of subscribers, an increase in demand for unique video programs requires additional investment in the feeder plant and video switching. Our model calculates an incremental capital cost of $50 per

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[7] Profound changes in the economic and regulatory environment would have to occur before any such joint ventures between LEC's and CATV operators could be envisioned.

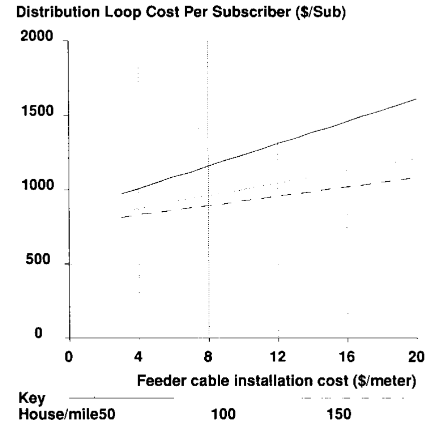


Fig. 5. Conventional copper loop plant versus subscriber density and installation cost.

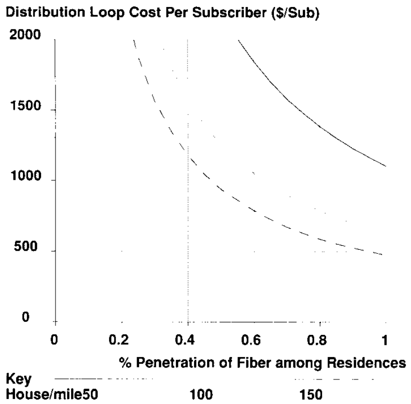


Fig. 8. Average cost per subscriber for switched star from CO.

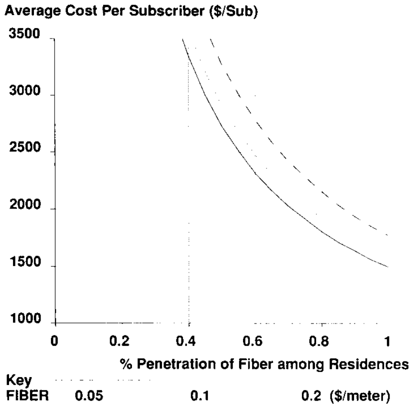


Fig. 6. Average cost per subscriber for active double star.

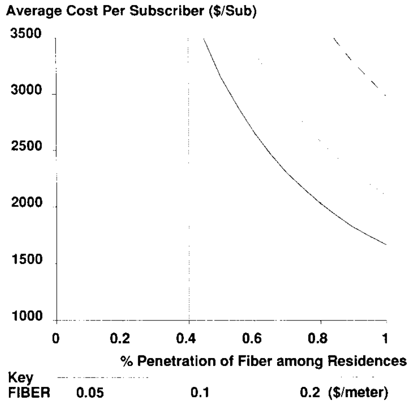


Fig. 9. Average cost per subscriber for passive star using TDM.

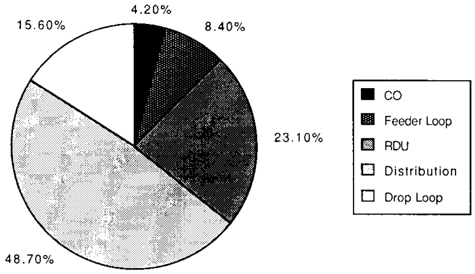


Fig. 7. Total cost distribution at 60 percent penetration.

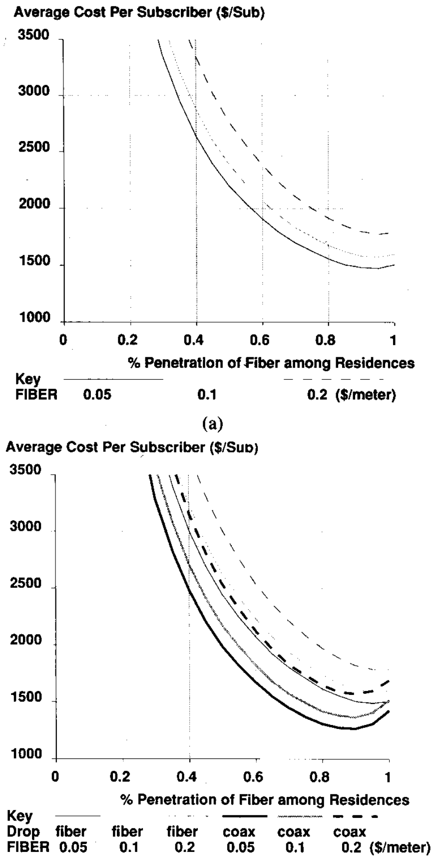
subscriber that would result from an increase of one erlang per subscriber in the average use of the network for on-demand video. An increase of one erlang in average weekly viewing implies 52 additional revenue generating hours per year to recover this capital cost. Thus an incremental capital cost of $50 can be recovered in three years through a charge of only $0.33/hour for on-demand video service. Viewed as an incremental cost above a base cost for a CATV-like service, on-demand video can be provided for a relatively low communications cost.

C. Switched Star

The active double star model employs electronics at the RDU in order to reduce dramatically the amount of fiber which must be installed by comparison with the single switched star. Equally important, in an environment of uncertain penetration, the active double star reduces fixed investment in fiber plant in favor of incremental investment in switching. Even at 100-percent penetration and a very low assumed cost for fiber, it appears that the double star is a superior solution (Fig. 9).

D. Passive Double Star

The analysis suggests that a passive double star architecture is slightly less expensive than the active double star (Fig. 10(a)). Compared to the double star, the passive star uses more feeder fibers; in the distribution portion, the passive star uses less fiber (see discussion supra footnote 3).



(a)

(b)

Fig. 10. Comparison of average cost per subscriber for (a) all-fiber passive star versus (b) fiber plus coax/copper drops.

E. Combined Fiber and Coax

As discussed above, significant economies might be available if existing coaxial cable and copper pairs are used for the final drop to the household. Unlike the passive star, this approach requires power to be delivered to each terminal where the optical signal is converted to an electrical signal on the coax. Fig. 10(b) shows the potential savings that might result from a joint venture between the LEC and the CATV operator. This option clearly has lower costs than any other design considered in the study.

V. CONCLUSIONS

There are a number of conclusions to be drawn from this preliminary analysis of FORSN. First, it is clear that running fiber to the home, even assuming significant future reductions in component costs, is likely to remain more expensive than new copper, where current loop plant costs are roughly $1000 per subscriber. To realize the introduction of a FORSN, it must be justified on the basis of additional revenue producing services, such as the delivery of entertainment video.

Second, the analysis suggests that a fiber optic network capable of providing both voice and video services to the home can be constructed for less than $1500–$2000 per subscriber. The cost is in the range of the combined cost of a CATV and telephone network only if fiber-based services realize near universal (~ 85-percent) penetration.

Third, there exist a number of architectures which reduce the amount of fiber required in favor of remote electronics or optical equipment. To the extent that electronics costs can be reduced to the levels we project, such designs can significantly reduce the total cost of the loop plant.

Fourth, the high installation costs for fiber argue for installing adequate capacity at the beginning to handle all subscribers in a serving area. In order to minimize the initial fixed capital investment, and the resultant economic risk that usage might not materialize at forecasted rates, it is desirable to select an architecture which trades fixed costs for equipment costs which are only incurred on an as-needed basis.

Fifth, with respect to alternative architectures, some form of double star—whether passive or active—seems preferable to a single star on the basis of fiber cost savings. At the same time, total costs are more sensitive to variations in subscriber density or installation cost than to fiber cost. Other architectures, such as a bus, remain to be studied. It is still too early, given the rapid pace of development in electrooptics technology, to determine a single optimum architecture.

With respect to the two double star designs, the cost of an architecture based on passive splitters is comparable to the active double star, which requires more untested electronics. However, pending the development of coherent modulation and detection techniques, or inexpensive components for high density WDM or TDM at gigabit speeds, the passive architecture studied here is limited to the carriage of NTSC as opposed to EQTV or HDTV signals. A judgement as to when support for the latter is required relative to when improved electrooptics will appear is needed to assess the importance of this limitation. The passive double star has a potential privacy problem since the signals for several households are carried on the fiber coming into each home. These signals are demultiplexed in the network circuit terminating equipment (NCTE) and only the signal destined for the particular home is passed to the codec. Security would be less of a problem, though by no means eliminated as an issue, if the NCTE could be treated as carrier rather than customer equipment, allowing the carrier to guarantee its integrity. Such a designation runs against current trends in FCC rulemaking [10]. Finally, significant cost savings can be achieved by reusing, when possible, the existing copper pairs and coaxial cable drops in conjunction with fiber delivery.

A. Policy Implications

These engineering and economic conclusions have a number of policy implications.

If the success of a FORSN requires revenues from the carriage of entertainment video, then one would expect intense lobbying from the local exchange carriers (LEC's) to ease the restictions which currently restrict their entry into this market. [11] The FCC has already recommended that Congress ease the cross-ownership restrictions imposed by the Cable Act of 1984. Further, the entry by the LEC's into video carriage will raise again the question of whether video signal distributors should be treated as publishers or as common carriers [22]. The LEC's have been lobbying heavily to have the MFJ's restrictions on content origination lifted so that they might participate more fully in the videotext marketplace. However, an LEC freed from the need to separate carriage from content would be much more threatening if it was then allowed to combine with or displace CATV operators to become the monopoly provider of wired video to the home. The LEC's may well need to choose between government approval to become the monopoly supplier of wired video to the home, and freedom to originate content on their networks. They are unlikely to receive approval for both, at least not without strong safeguards such as a requirement for maximally separated subsidiaries.

Second, the high ratio of fixed to variable costs poses problems in terms of accounting for investments in—and pricing of services provided by—a FORSN. There is a risk that LEC's will invest in fiber installation, only to find that penetration of video services remains stalled at 20 or 30 percent. Under such circumstances, there may well be a tendency to attempt to distribute the costs of such investment over all local telephone ratepayers, including those who were perfectly satisfied with services provided over the old copper plant.

Whether or not this is desirable as a policy matter is certainly open to debate. Some would argue that it is an appropriate way to encourage the introduction of new technology which will ultimately become universal. Others might take the position, as we have in the presentation of our results, that only subscribers of the new broad-band services should bear the costs of fiber installation. If the latter view is taken, estimates of future penetration rates will be a critical element of debates over the proper "cost" per subscriber of the loop plant. Optimistic estimates of penetration can lead to under pricing, and either substantial under recovery of capital investment, or a shift of the capital costs to other ratepayers. The latter outcome will be difficult to avoid, especially if fiber installation is lumped with other investments in loop plant. As analyzed here, a FORSN clearly falls under the category of a "basic" service. As such, investments in fiber in the local loop are included for ratemaking purposes with investments in copper loop plant. Attempts to separate investment in a FORSN so as to avoid these problems will likely founder on the inability to distinguish between fiber installed in anticipation of eventual video delivery, and fiber installed today to reduce the cost of copper in the loop plant through multiplexing.

A State Public Utility Commission faced with a request by the local exchange carrier for a certificate of "public interest convenience and necessity" to construct a FORSN has a difficult decision to make. The PUC's burden can be eased if there is some way to shift the risk of failure away from the POTS ratepayer. The LEC can better its chances for PUC approval if it has a long-term contract with a cable operator to provide video transport services over a FORSN. Such a contract shifts the subscriber penetration risk from the regulated PUC to the unregulated cable franchise. However, a FORSN threatens the cable operators's franchise monopoly, for it makes it possible for there to be many sources for video programming.[8]

Finally, if the PUC's were to move from overall rate of return regulation to a price cap on basic voice service, then the risk of the investment in a FORSN can be shifted to the shareholders of the LEC [19]. Since revenue from POTS is capped, in theory any losses which result from a failure to correctly gauge the market for a FORSN could not be passed on to the POTS ratepayer. By the same token, the LEC would then be in a position to reap fully the rewards of establishing a successful FORSN.

In sum, the broad-band ISDN threatens to abolish forever the distinction between point-to-point and mass media, and force a collision among two long separated traditions of public policy and regulation.

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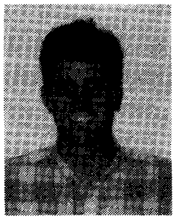

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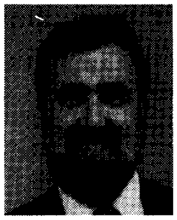

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