Deep Fiber Networks: New, Ready to Deploy Architectures Yield Technical And Economic Benefits

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Abstract

The cost of running fiber deeper—to the extent of achieving passive and near passive cable architectures has been dramatically reduced due to recent advances in HFC access network components. This paper explores various technical and economic aspects of "deep fiber" architectures, and how the rapid evolution of 1550 nm EDFA's, optoelectronic receivers, passive optics and an optimization of HFC network elements such as transmitters, nodes, and the return path can now yield substantial network improvements for a deep fiber environment.

ADVANCED SERVICES: THE NEED FOR BANDWIDTH

The advent of digital technology in HFC networks has opened up a myriad of opportunities for MSO's. MPEG compression of video streams has allowed for a near order of magnitude increase in the video capacity of a single channel such that more and varied basic broadcast programming can be offered in the same channel space. Video Servers have made possible the distribution of prior pay per view movies in the near-video-on-demand (NVOD) format and the soon to be available video-on-demand (VOD) service. Video in the HDTV format is now beginning to be available from broadcasters, and its availability will only increase with time.

In addition, digital technology has allowed for non-video services to flourish. The DOCIS standard has created an avenue for receiving high speed internet access, and both circuit switched and IP based telephony services are either now available or in advanced trials. Synergistic services, which make use of voice, video, and data simultaneously are in the concept and advanced development stages and should be available within 5 years.

The introduction of these advanced services comes at a cost: namely, the need for increased capacity, and especially increased reusable bandwidth. In HFC networks all services are ostensibly broadcast: the prime difference between services being the footprint over which these services are broadcast. Channel Lineups for broadcast video services typically cover the largest area. Advertising zones are typically second, usually on the order of a typical 20 k home hub. For initial penetrations for high speed data services such as cable modems, a typical hubsite will be divided into several sectors using a single 6 MHz channel. Telephony services are broadcast over the smallest area, typically a 6 MHz Channel for each node. Naturally as penetration of these services increase, the broadcast area for each of these services will also decrease.

Video: Multiple Customer Types

As interactive digital set top boxes are deployed, and as digital ready TV's become available, the types of customers served by MSO's will increase. An MSO today really only has to be concerned with two types of subscriber. Those with set top boxes and those without. With digital service rollouts the types of customers will increase to cover the permutations of those subscribers with analog or digital TV's and those with analog, digital or no set top box at all. Since Cable TV is still a fairly high penetration service, MSO's will still need to offer video services to all types.

This point makes its impact in several ways. First, even after the rollout of digital services, large numbers of purely analog subscribers will remain, accustomed to the 80 to 96 channels of analog programming available to them, so it will be difficult to remove those channels for use as digital programming. Second, pending must carry rules for new DTV and HDTV programming could require MSO's to provide these channels also. Finally, off air digital programming will be in a multilevel VSB format while HFC channels from the headend are modulated via QAM formats. Some simulcasting of digital broadcast channels may be required to satisfy the needs of these two types of subscribers. The net of these changes is that a large amount of spectral channel allocation will be taken up by broadcast services leaving less room for advanced interactive services.

Data and Voice: The Need for 2 Way Bandwidth

As data and voice services are deployed over the next few years and the penetrations of these services grow, the need to allocate capacity and hence bandwidth to these services will also increase. For network simplicity reasons most MSO's are allocating one or at most two 6 MHz channels each for cable modems and telephony. Therefore, as capacity needs increase, the area over which each of these services are broadcast will have to decrease.

For cable modems this need for additional capacity is further exacerbated by the developing use and maturity of the Internet. Current cable modem deployments are allowing for a minimum available data rate of about 128 kbs allowed per user. While this rate is a large improvement over current telephony based modems, the availability of downloadable video clips will put pressure on MSO's to increase dramatically this minimum available data rate.

For cable telephony, several providers are discussing plans for offering as many as 4 telephone lines per subscriber and offering at least one of them as an "always on" data channel. For current systems allocating one telephony channel per typical 500 home node, the "logical node size", i.e., the area over which this service will be broadcast, will have to be reduced even further.

These constraints are illustrated in figure 1. As can be seen, the inclusion of large numbers of analog channels for non set top subscribers, HDTV channels in possible must carry scenarios, advanced services such as NVOD, and VOD, data, voice and other services can push the required bandwidth in excess of 1 GHz! Since most systems are being upgraded to 750 MHz and possible 870 MHz,

Service	Fwd B/W Range (MHz)	Reverse B/W Range(MHz)
Broadcast Analog	500 - 700	2
Broadcast Digital	18 - 24	2
NVOD	36 - 96	2
VOD	24 - 36	2
HDTV	12 - 66+	—
WEBTV	6	2
Television Based Data Services	6	2
PC Based Data servicess	6	4
Worldgate	—	2
Targeted Advertising	12 - 36	TBD
Cable Telephony	12	12
IP Telephony	3 - 6	1 - 3
IP Videoconferencing	3 - 6	6 - 12
Multimedia	TBD	TBD
	638 - 1000MHz	35 - 44MHz

Figure 1. Service Spectrum Allocation

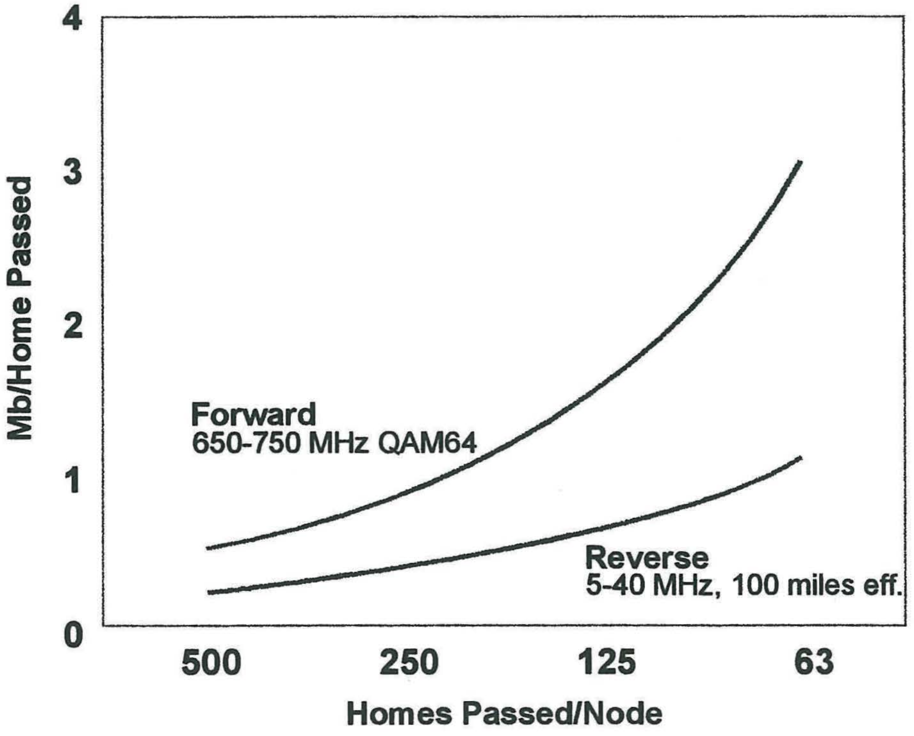

Figure 2. Available Bandwidth/Home Passed

clearly something will have to be done to accommodate these demands. One logical solution is to allocate less bandwidth to the interactive channels and reuse this spectrum over and over again by reducing this logical node size for the interactive channels. From the standpoint of the reverse channels, similar problems are seen, causing the need for smaller logical node sizes to be even more pronounced. In addition, for ingress and channel redundancy issues, not all of the 5 MHz to 40 MHz bandwidth is available. Figure 2 shows the available reusable bandwidth as the node size is reduced from 500 homes to 50 homes passed in a typical 80 – 100 home per mile plant. It is envisioned that nearly 2 Mbs per home passed will be required within 10 years. If we consider optimistic projections for service rollouts and penetrations, this number could be considerably higher.

ADVANCED SERVICES: THE NEED FOR RELIABILITY

In addition to increased capacity in both the forward and reverse path, increased network reliability is also a primary consideration. Two key means for increasing the reliability of a network is to reduce the amount of coaxial cable in the plant and to reduce the number of active devices in the field. Figure 3 illustrates the number of active devices such as RF amplifiers in a plant as the physical node size is reduced. A minimum in the number of actives (and hence the maximization of the reliability of the plant) is achieved at the passive cable point: the point at which no additional actives are needed. As the node size is reduced further, additional fiber optic receivers are needed and the number of actives increases. Also in figure 3 the amount of power needed per mile of plant is shown.

DEEP FIBER ARCHITECTURES

A typical Deep Fiber Architecture is shown in figure 4. While from the diagram it is very similar to standard HFC networks in several respects, it contains important differences as well. First, typical HFC networks are based on logical node sizes in the 1000 to 2000 home range. As logical nodes sizes approach the passive HFC point, the amount of independent (non broadcast) information delivered per mile of plant goes up dramatically. For this to occur the processing equipment at the hubs, or the DWDM networks required to remote the hub equipment to the headend must become more extensive. Second, the increase in the number of fibers employed in these fiber deep architectures must be handled by in field splitting or in creating smaller hub sizes. Finally, driving fiber deeper in the network results in the reduction in the numbers of RF amplifiers in cascade so the performance required by each of the elements in the network can be re-optimized to this new configuration in both the forward and reverse.

DEEP FIBER TECHNOLOGY

Since Deep Fiber architectures employ substantially more opto-electronic components than standard HFC architectures, the steep improvements in both the cost and performance of optoelectronic technology and optoelectronic devices have had a major impact towards pushing fiber deeper. HFC transmitters and

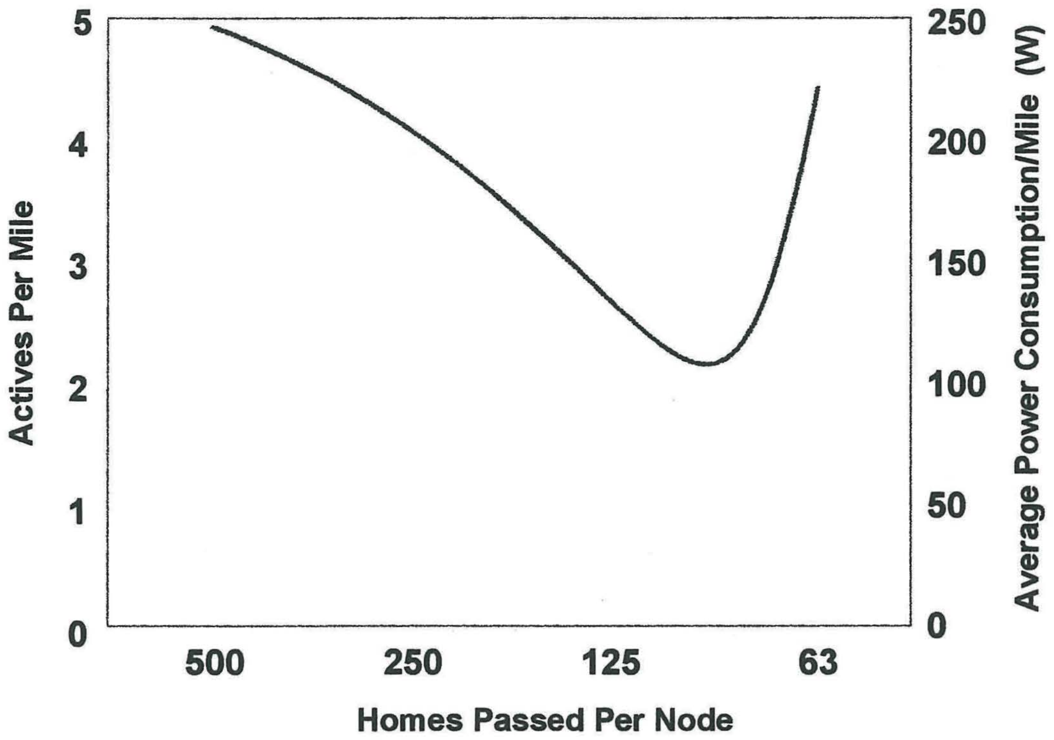

Figure 3. Actives and Power Consumption Per Mile as Fiber Goes Deeper

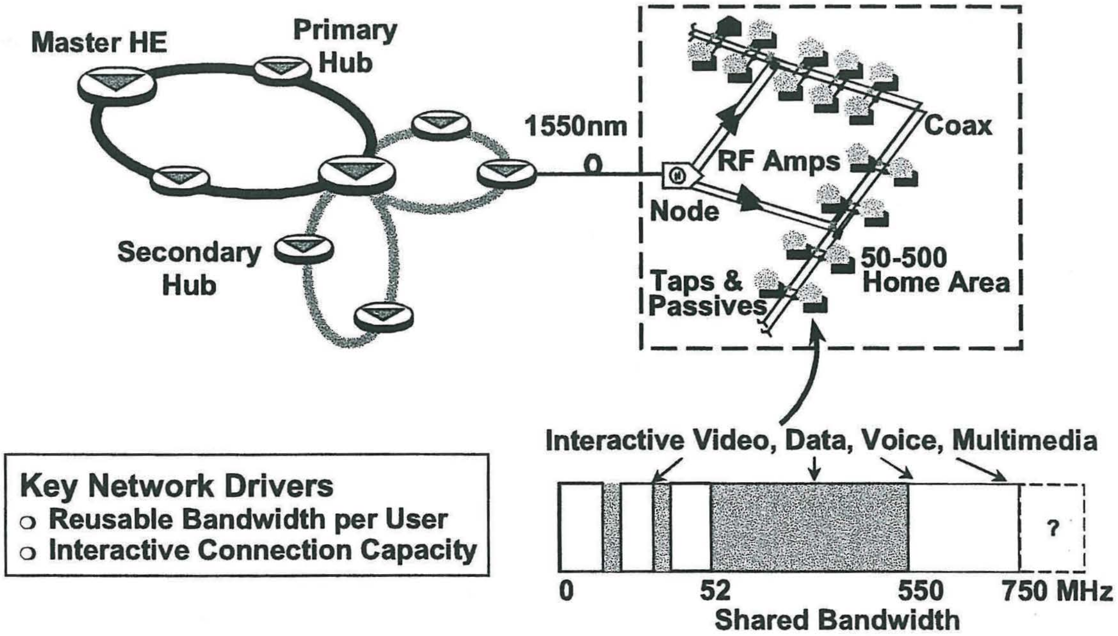

Figure 4. HFC Deep Fiber Architecture

receivers, as well as fiber optic passives such as splitters and multiplexers have seen major improvements in terms of performance, reliability, and cost.

DWDM Technology and High Power Optical Amplifiers

Another area where opto technology development is having a large impact in the deployment of deep fiber systems is in the introduction of 1550 nm transmission technology with high power optical amplifiers, DWDM transmission, and WDM overlay technology. Figure 5 shows the progression of the cost of transmitting light at 1310 nm and at 1550 nm. As will all laser based systems, the cost of generating light per mW decreases as more of it is created. Secondly, the reductions in cost per mW year over year are the result of technology learning curve improvements. It can be seen that 1550 nm transmission technology is on not only a much steeper learning curve, but also moving to higher powers and hence lower $/mW transmission costs.

Since in nearly all HFC networks the majority of the traffic is broadcast, systems can be designed which take advantage of the low costs afforded by 1550 nm high power optical technology. For narrowcast traffic, DWDM transmission and overlay technology allows the narrowcast portion of the HFC spectrum to be transmitted separately and hence each portion of the transmission can be optimized independently. At the headend, the QAM modulated interactive narrowcast channels are mapped to an optical wavelength and transmitted to the hub via DWDM. At the hub, the narrowcast DWDM channels are optically routed to their respective node or groups of nodes, where the narrowcast and broadcast portions of the spectrum are combined optically on a single photodetector. The different RF spectrum of the broadcast and narrowcast traffic allows for this to be accomplished without interference.

Performance Improvements

In Deep Fiber HFC networks, there are up to 10 times as many nodes as in a traditional 500 home node network. At first glance, one would assume that the optical transmission system would have to supply 10 times the optical power for the broadcast traffic to maintain adequate CNR levels. Figure 6 shows that this is not the case. As fiber goes deeper into the network, and the RF amplifier cascade is eliminated. The specifications usually reserved for the fiber optic node become the same as the end of line spec. In this configuration, the optical modulation index of the 1550 nm transmitter can be increased such that the fiber optic link performance matches the end of line requirement. With this, the optical power required at the node to maintain adequate CNR levels may be reduced substantially. In fact, for an order of magnitude increase in the number of nodes in a Fiber Deep Network, only 3 dB extra fiber optic broadcast optical power is required.

DEEP FIBER ECONOMICS

Despite the advantages gained in terms of network capacity, performance and reliability when fiber is pushed closer to the home, the high cost of such systems has been the major stumbling block to the adoption of Deep Fiber Networks. When most operators began their plant upgrade plans a couple of

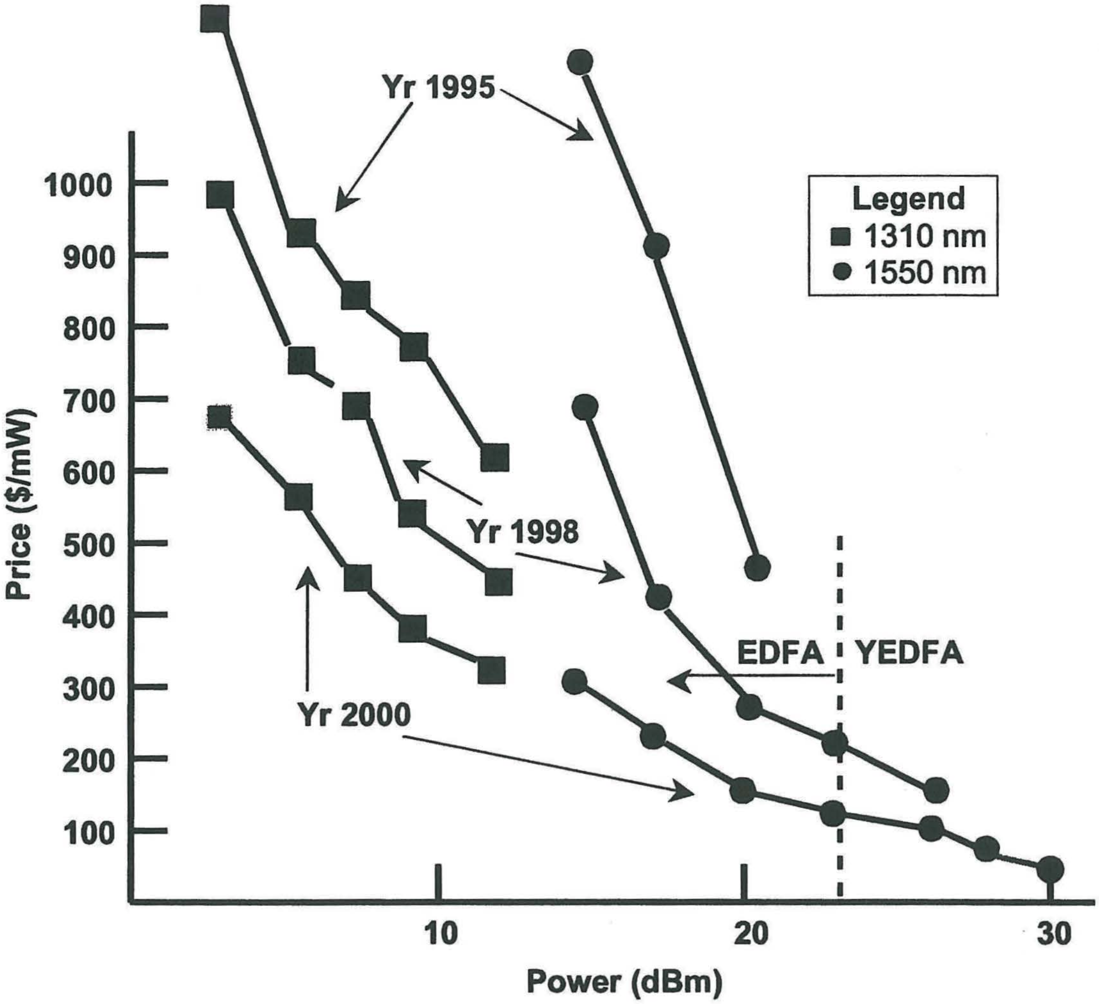

Figure 5 Transmission Power/Cost Trends

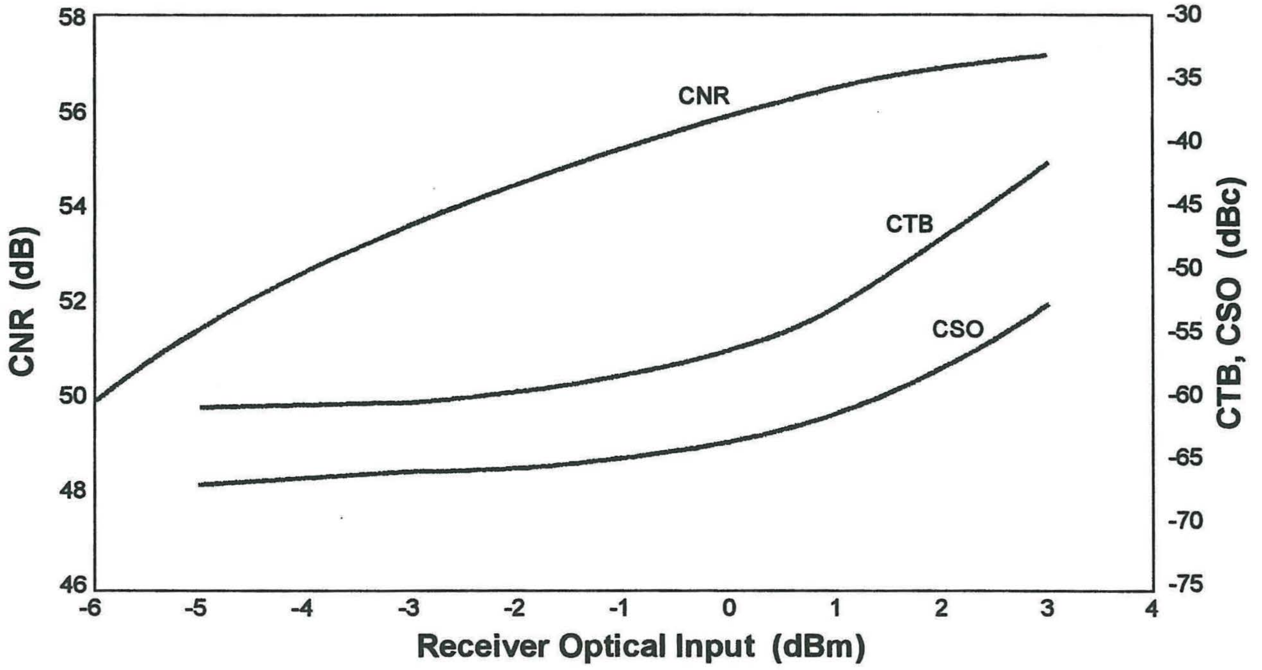

Figure 6. Fiber Deep Node Performance

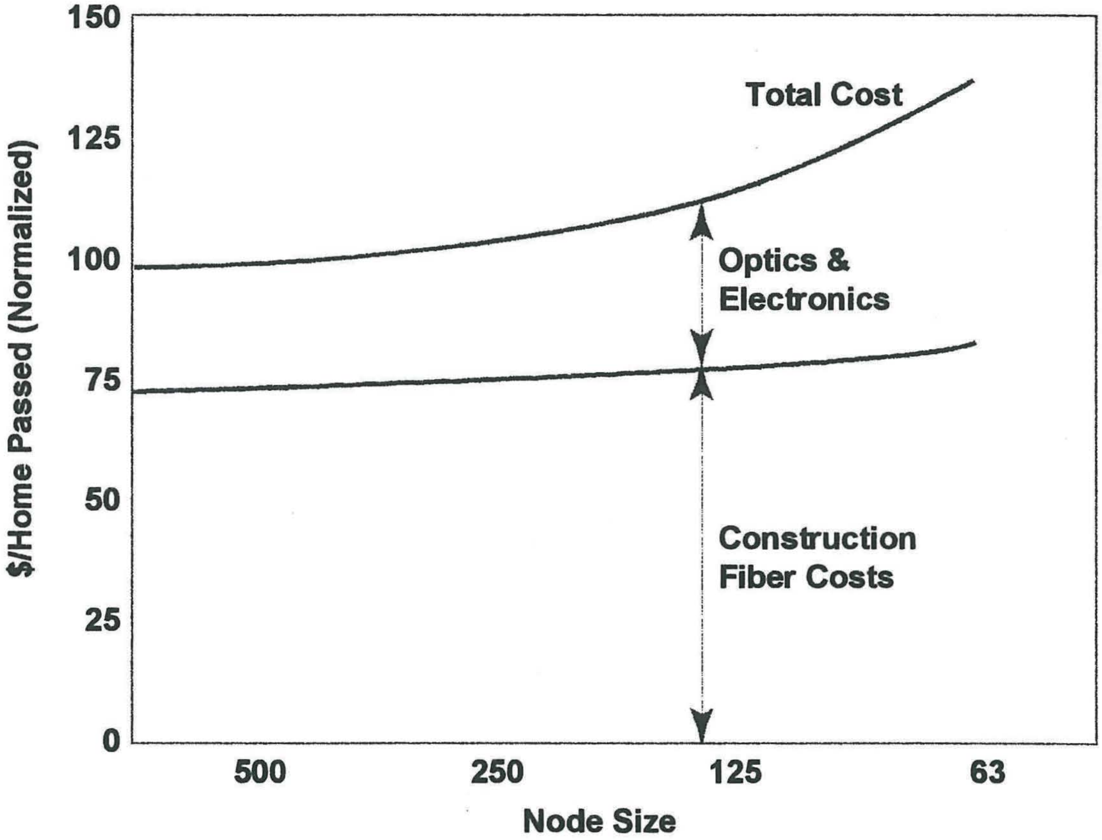

Figure 7. Plant Costs as Fiber Goes Deeper
(100 = $/Home Passed for 500 Homes)

years ago, 500 home nodes were the limit for how deep fiber could go in an HFC network. Improvements in optoelectronic components, new transmission techniques, and reduced cost of optical fiber have caused this fiber limit to be pushed closer to the home. Figure 7 illustrates these improvements. From this graph, we see that the premium for driving fiber to the 125 home near passive HFC architecture is less than 10% the cost of rebuilding a 500 home HFC network. For passive networks, the premium is about 40%. Also from the graph, it appears that about three quarters of the cost is in fiber and construction, while the contribution from electronics cost grows as fiber goes below the near passive point. As the optics and electronics costs continue to fall, it is expected the costs of passive HFC networks will drop to levels close to current HFC plant costs.

CONCLUSIONS

The arrival of advanced interactive services will place great demands on improving network capacity, reliability and cost. Continuing improvements in optoelectronic components, network architectures, and transmission techniques such as DWDM, are allowing fiber to be driven closer to the home, achieving the network improvements such as increased reusable bandwidth per subscriber, higher reverse path performance, reduced network power consumption, and higher network reliability all at a cost inline with current HFC plant costs.