CONSIDERATIONS FOR DEVELOPMENT OF EXISTING CATV NETWORKS FOR FUTURE TELECOMMUNICATIONS SERVICES

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A major portion of the current CATV systems in the United States have yet to be upgraded. A lot of work has been done on reducing amplifier cascades with fiber, and a few companies have started implementing their best guess of what a future Hybrid Fiber Coax (HFC) network should look like. Not to belittle anyone's efforts, but everyone is guessing! Almost every new service being proposed today has been talked about since the late sixties. The major drawbacks to implementing most of these services are both technical and sociological in nature. The Warner "Qube" project and at least one videotex experiment that I am aware of are examples of technologies deployed before their time. Over the last few years there have been several breakthroughs in fiber optics and communications technology, and integration in the computer industry has made many of these services technically viable. Much of the uncertainty surrounding how to build a HFC network centers around which of these services will be marketable and how much demand there will be for them.

From a technical point of view, the best answer to this uncertainty is to build a network which is flexible enough to handle any foreseeable situation. While this is very attractive to the engineer, it may not be very practical -hence, the educated guess.

All else aside, the cable industry has the unique ability to do two things very well: broadcasting and narrowcasting. Our competitors may be able to do one or the other, but not both with any reasonable degree of efficiency. Broadcasting multiple analog telecommunications signals has been our bread and butter. It will continue to be a very important part of our success in the future - after all, there are several hundred million analog TV sets in the US alone. With the advent of fiber and other related technical advances, we should be able to overlay an efficient and reliable high speed digital network in place, which will allow us to narrowcast individual services to our customers. Achieving this mix in an efficient integrated network is what will allow us to survive in the future. The remainder of this article will discuss several of the technical issues surrounding the requirements and concerns of providing these proposed future services.

Architectures

A network must be both flexible and reliable enough to allow for future services. Most of the current HFC designs have a common thread. A service area is defined, based on a specific category such as homes passed, and a fiber optic node is placed in a convenient location to serve that area. The services are then distributed throughout the area using a coaxial bus. The size of the service area, the number of fibers allocated, the amplifier cascade allowed in the bus, redundancy, path diversity, noise and distortions, etc., are all factors that vary widely across the industry. No matter which version of HFC architecture that one is deploying, it is significantly better for distributing the traditional analog broadcast channels than a long cascade, as in the branch and tree systems of the past. Narrowcasting has become the driver for network design.

The concept of narrowcasting changes dramatically the way one must think about system design. In a traditional cable television headend, 99+ percent of the signal sources go to every subscriber. To narrowcast, one must be able to supply a set of unique services to each individual subscriber. Hence statistical traffic capacity analysis must be incorporated into network design. Also, if one believe that a lifeline telephone service is in one's future, and that it will be network powered, variable current and voltage loading concerns must be addressed. A separate section discussing powering issues will be presented later.

What we don't know about the services littering the information super highway is scary. What we must do is proceed on one's best educated guess. For example, Video On Demand requires a 3 to 5 Mb/s downstream capacity for each unique user, but only a bursty, very low data rate capacity upstream. Video telephony, on the other hand, will probably require a symmetrical 384 Kb/s per active caller. These are two of the most talked about services, and are also the biggest wildcards with respect to network loading. If one chooses a 25% peak loading in a 60% penetrated 500 home service area, VOD service will require approximately twelve individual 6 MHz wide Quadrature Amplitude Modulated (QAM) downstream channels: (4Mb/s *.25*.6*500 homes)÷27Mb/s. OK, but what if your penetration varies between 10% and 95%, or a particular neighborhood has an atypical number of VOD customers on a given day? There are three main choices: 1) Ignore the problem and eventually sell your system, 2) build a Rolls Royce network that will not run out of capacity but will cost so much you may never break even or, 3) build a system with the flexibility to change with the business as necessary.

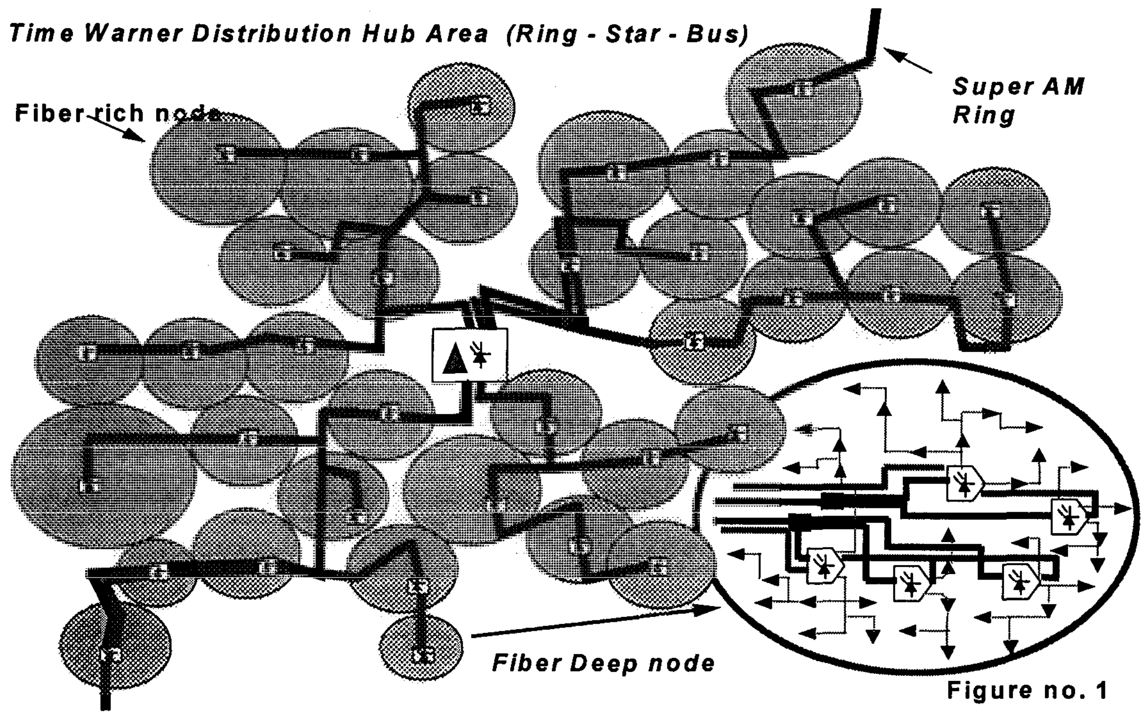

Figure no. 1

One of the first decisions to make is the size of the service area. Today, one's choice should be based on an acceptable set of analog video distortions, a reliability factor one can live with, and a cost effective migration path to a smaller service area that can be overlaid onto the existing network with a minimum of rework and customer disruptions. Our experience with reliability has been that as the amplifier cascade increases, reliability decreases on a logarithmic basis. On the other hand, a purely passive coaxial bus is very expensive and does not yield significant gains in reliability over a HFC design with short cascades. A recent paper on reliability(1) suggests that system availability differences between passive and near passive HFC designs are less than three minutes per year. The current difference in upgrade cost between these two approaches is several thousand dollars per mile.

Next, fibers are home run from service areas to the hub; enough fibers are used to provide flexibility. In many cases the labor expense of installing a fiber optic cable may cost more per foot than the cable itself. It also may pay to consider increasing the number of hub locations in the system. By shortening optical paths to the service areas, one can save "up front" on the cost of laser transmitters and high fiber count cables. In many cases, this monetary difference is more than enough to pay for the land, building, and electronics. It is also presents an opportunity to provide path diversity and electronic redundancy at a location which is reasonably close to the customer, without an exorbitant price penalty.

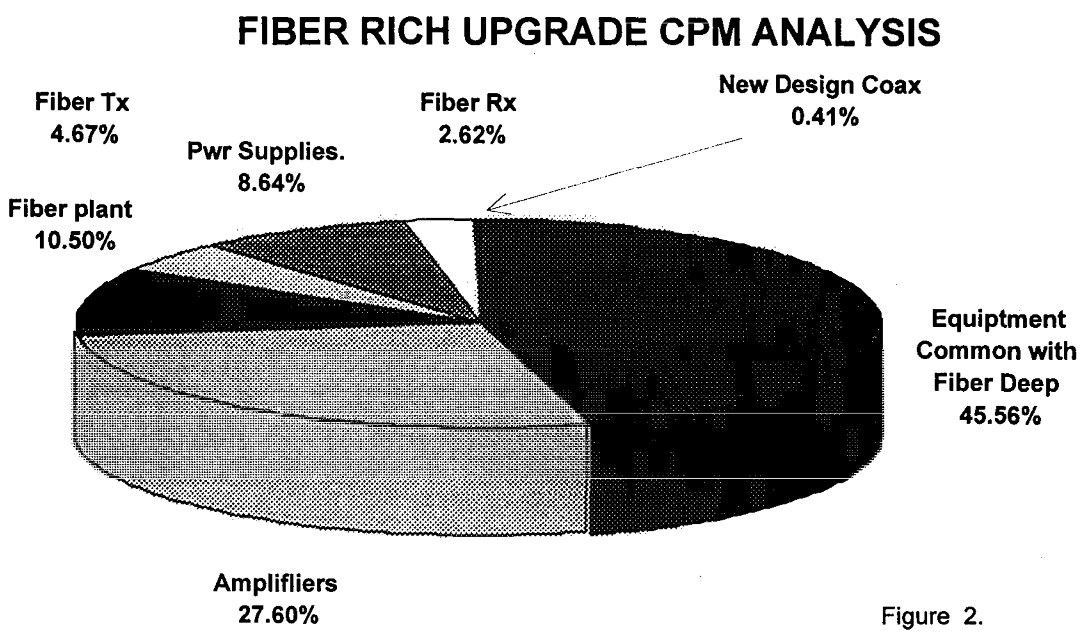

Figure 2.

Time Warner has developed a Ring-Ring-Star-Bus architecture as a compromise between current and future needs. The service area averages 500 passings and hubs serve roughly 40 service areas. This gives us very short optical path budgets and limits our exposure to loss of service from damage to the star(Figure 1.). Presently, Time Warner is using a coaxial bus architecture called Fiber Rich. This design calls for a maximum cascade of two trunk amplifiers, one bridger, and three line extenders. This cascade allows us to easily serve 500 passings where densities are greater than 50 hpm. This design has also been fairly cost effective, upgrading the typical 300 MHz system to 750 MHz using one GHz taps and passives with an average costs per mile in the 12 to 14 thousand dollar range (Figure 2.)

Fiber Deep

Because the price of fiber optic cable and electronics has been steadily decreasing, we are now able to move fiber optics deeper into the existing coaxial plant. This new architecture is called Fiber Deep. To prove the feasibility of this new design, we performed cost analysis on several test designs, with various ratios of fiber to coaxial plant.

Fiber Deep is a modified fiber to the bridger architecture. Our analysis indicated that pushing fiber beyond this point in the plant was costly and provided very little improvement in efficiency or reliability. Fiber Deep, on the other hand, trades the cost advantages of fewer amplifiers and power supplies against increases in fiber optic cable and electronics.

MONROEVILLE SERVICE AREA COMPARISON				
Service Area	Feet of coax	Miles of coax	Amplifiers	Amplifiers per mile*
Fiber Deep #002	29389	5.57	30	5.39
Fiber Deep #003	22965	4.35	24	5.52
Fiber Deep #005	17080	3.23	16	4.95
Fiber Deep #095	10625	2.01	10	4.97
Fiber Rich #001	15323	2.90	18	6.20
Fiber Rich #010	34070	6.45	36	5.58
Fiber Rich #021	34357	6.51	43	6.61
Fiber rich #036	17548	3.32	24	7.22
Fiber Deep Total	80059	15.16	80	5.21
Fiber Rich Total	101298	19.19	121	6.40
Overall Total	181357	34.35	201	5.80

*Does not include receiver / launch amplifier

Table 1.

Initial results of the Fiber Deep architecture study turned out to be slightly less expensive than similar plant sections designed using the Fiber Rich method. The simpler amplifiers and reduced cascades should also yield better long term operating cost and reliability.

The coaxial bus design of Fiber Deep has an optical node capable of bridger output levels and up to three line extenders in cascade. The existing trunk system is used to transport power and upstream signals within the service area. The reduced cascade allows for higher output levels at the same end of line distortions. These higher levels allowed use of fewer amplifiers per mile than required in the Fiber Rich architecture (Table 1.).

The optical network in Fiber Deep builds on the concept of having several fibers from the hub to the 500 home service area (six in Time Warner's case). Within that area, one or more field splits may be deployed to serve as many as four optical receivers. The fiber network is easily reconfigured for any combination of upstream transmitters and downstream splitters necessary to accommodate network traffic growth with very little additional cost and few customer interruptions.

Starting in mid 1994, Time Warner established a field test of the new architecture in Monroeville, PA. The system is a 330 mile plant in the suburbs of Pittsburgh, PA , with an average density of 145 homes passed per mile. Two hundred miles of the system are being upgraded using the Fiber Deep design. Fibers are split both at the hub and in the service area to provide optimum utilization of the optical power produced by today's laser transmitters.

FIBER DEEP UPGRADE MAJOR COMPONENT CPM ANALYSIS

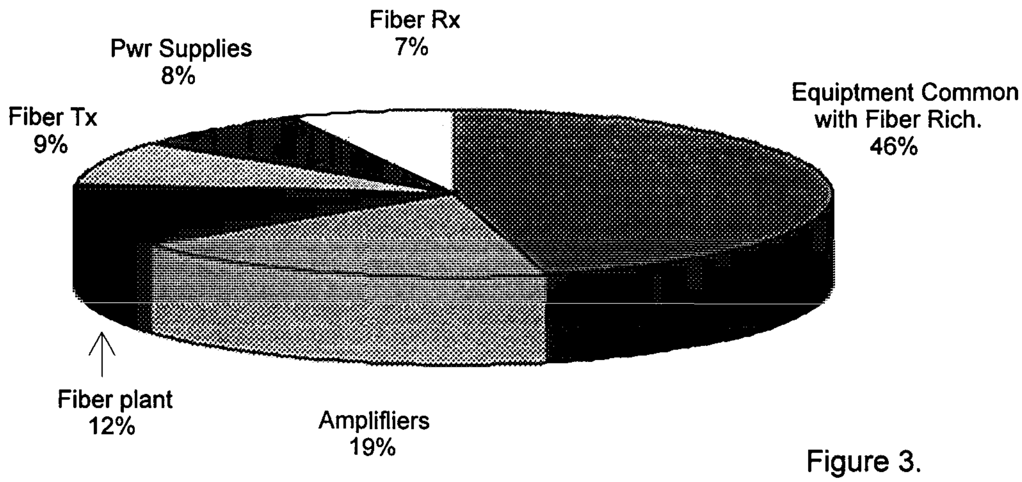

Figure 3.

Figure 3. shows the Fiber Deep architecture in percent of cost per mile of the major categories. The field numbers tracked our original paper study with an error rate of less than one percent. Besides having some operational and reliability efficiencies, the design also lends itself well to the implementation of HFC network powering of telephony. We feel that the concept should be cost effective down to the 70 to 80 hpm densities in plants where the trunk is 90 % or more aerial. The data used in this analysis represents 10% of the actual plant area. A more complete analysis should be available by mid 1995.

Narrowcasting

As stated earlier, narrowcasting provides for real time, high speed, switched data services to be made available to our customers. Time Warner is currently reserving the top 200 MHz of all 750 MHz upgrades for these services. Our goal is to be able to deliver unique data streams to each service area, when the business dictates.

Today the most cost effective DFB laser transmitters are in the 8 to 10 mW output range. To utilize this much power, we must split the outputs to an average of four service areas, or 2000 homes passed per laser. The DFB laser manufacturers have yet to offer a cost equivalent lower power laser.

This may be the wrong way to look at solving this dilemma. True, the fiber architecture that is being incorporated calls for very short path budgets, but the objective is to be able to uniquely modulate each path. Maybe the answer is to split a high power laser source, then externally modulate the outputs to each service area. We may even be able to back up the laser source, solving some of the reliability issues surrounding the MTBF of DFB laser transmitters.

Traditional Powering Architectures

The convergence of traditional CATV services with digital narrowcasting, and the advent of telephony over HFC have caused an increased focus on power delivery architectures. These architectures and the practice of powering design have not changed since the move from 30 to 60 Volts twenty years ago. The next several sections are devoted to a reexamination of these practices.

Telephony Differences

Deployment of lifeline telephony service has placed new constraints on traditional powering architectures and design techniques. Time Warner Communication's current belief is that in order to maximize the market potential of telephony over coax, a prospective subscriber must perceive no difference in the nature, quality, and reliability of this service. These requirements have two important impacts on powering:

- In order to meet or exceed the traditional service availability offered by the local exchange carrier (LEC), a highly reliable powering architecture offering extended standby time (eight hours or longer) is required.
- Provision of telephone service must be accomplished without the need to place equipment inside or otherwise enter the subscriber's residence. This requires subscriber interface electronics to be powered from common (shared) network power sources.

Increasing System Availability

System availability can be expressed in terms of subscriber-minutes per year of outage time: the outage time experienced by the *average* subscriber each year. In order to compete effectively with an entrenched LEC, the existing CATV network must be upgraded in a way that efficiently utilizes the embedded capital investment, and speeds the deployment of new services. These two requirements preclude the use of techniques which require a complete rebuild of the network. The fiber deep approach offers such efficiencies from an RF standpoint; The following concepts are being explored to accomplish similar advantages from a powering perspective.

Extended Backup Options

In Time Warner's approach to the provision of telephony services, common power sources used in network powered architectures must offer at least 8 hours of standby time. Initial cost studies indicate that battery only standby power sources cannot compete on an operational basis with genset based sources due to the cost of battery replacements. Power sources with output ratings at or above traditional CATV capacities require battery banks similar in installed cost to genset based systems. Battery only systems offer deployment cost advantages only where small capacity units are required. Large gensets cost only moderately more than medium sized gensets. Telephony service deployment increases the total system power load per mile, calling for larger capacity power sources. These realities dictate that the number of power source locations be reduced to take advantage of the economies of larger genset based sources.

Power Source Cascade Reduction

Power outages have historically been the most significant contributor to system outage time in the CATV industry. The standby power sources required by telephony services are expected to remain among the worst offenders in system availability calculations. As such, measures which reduce or eliminate subscriber service dependency on more than one power source (power source "cascades") have a disproportionately significant impact on improving system availability.

Single point node powering produces the maximum power system availability. In general, the 60 Volt design presently used in Time Warner's 500 home passed average nodes cannot achieve single point powering. Techniques under investigation to accomplish single point powering include use of 90 Volt power sources feeding equipment operating in a proportionally wider voltage range (to 40 Volts minimum), and the concept of node boundary determination based on power source service coverage areas.

Unfortunately, many existing CATV networks cannot be powered from a single location, even at the NESC codified limit of 90 Volts rms. This is due to network layouts that are "stringy" in nature, where loads are concentrated towards the ends of long feeders. This is often the case where natural and man made boundaries such as rivers and expressways prevent frequent interconnections. Low density networks are also difficult to single point power due to higher amounts of cable resistance for comparable loads. If node boundaries are determined by power source service area coverage in stringy and low density cases, optics cost would normally becomes prohibitive due to the small node sizes produced. The optical field splitting technique employed in the fiber deep approach addresses this concern from a forward RF perspective, and the presence of 4 or 5 unused fibers makes possible the deployment of additional return lasers for flexible sub-division of service area boundaries, to coincide with powering boundaries if necessary.

Design Techniques for Reduced Power Source Cascades

Two techniques are currently available to the powering system designer to help provide the lowest power source cascades to the greatest number of subscribers (recall that system availability is defined as outage time experienced by the *average* customer).

The first technique is to serve the greatest possible number of subscribers from a single point location, with the remaining voltage starvation cases addressed using an "extender" power supply. This supply would generally be a pole mounted low capacity unit offering 8 hours of standby time with batteries alone. Because of the limited number of subscribers served by the extender supply, the system availability calculation is not significantly impacted.

The second technique is to segment the node into "cells", taking care to place power source service area boundaries at the optical receiver location. Some type of switching methodology is then provisioned at the receiver whereby power failure in one cell will automatically switch the receiver power source to another cell. This technique maintains a power source cascade of one, with only a small reliability hit due to the automatic redundant source switch. This technique can be used to further subdivide a fiber deep service area below the level attainable through deployment of additional return lasers.

Another technique under investigation is the use of an autotransformer to step up voltage in order to address voltage starvation at the ends of long feeders. This technique is not available to designers because the required transformer and power removal/insertion device do not exist. The same technique could be used in reverse to limit power passing tap voltages in drop cables to 60 volts for power delivery to network electronics in locations subject to NEC regulations (inside buildings, etc.), while allowing use of 90 Volt transmission in the express portion of the network.

Dynamic Power Loads

The techniques described above are complex enough for the static loads of existing networks. Network powered telephony introduces two additional variables which vastly complicate the task of designing efficient powering architectures. These two variables are equipment usage patterns (traffic) and equipment deployment patterns (penetration rates and distribution).

Traffic

The leading proposals for the provision of residential telephony in existing coaxial networks employ an electronics package attached to the outside of the residence. This package is designed to closely resemble, and be located near the existing telephone network interface. This package, commonly referred to at the NIU, is being designed to minimize power consumption. As such, the NIU draws less power in the idle state than when subscriber telephones are off-hook or ringing. In the large sample sizes served by LEC switches, this traffic is well defined, and equipment can be provisioned for much less than 100% usage with a very low probability of call blocking. In the sample sizes typically served by a CATV power source location, this becomes a dangerous practice. If call volume is allowed to exceed the capacity of a given power architecture, then calls are not merely blocked; a shared outage is experienced by all subscribers in the affected area, including CATV customers!

The alternatives are to employ a software blocking algorithm to prevent such an activity, or to provision powering architectures capable of 100% loading. The software approach requires a complex software model of network topology, and is likely to produce blocking in excess of LEC standards if not accompanied by some degree of purposeful powering overdesign. The latter approach may be attainable at reasonable cost if deployed in conjunction with a solution to the more serious problem of penetration rates and distributions.

Penetration

Telephony penetration in the early years of deployment is expected to be relatively low, and even long term penetration is expected to be well below 100%. At first blush, this seems to be a ready opportunity for significant cost savings. However, two problems must be addressed before this cost savings can be realized.

Penetration Distribution within a Power Source Service Area

The first problem is caused by the uneven "lumpy" distribution of customers at a given penetration rate. The treelike nature of coaxial networks increases the likelihood of problems caused by concentrations of customers appearing in worst case locations such as the end of long feeders. These concentrations, in conjunction with the aforementioned traffic effects, have the potential to produce localized temporary outages due to voltage starvation conditions. These voltage starvation effects are best addressed by testing the powering design computer model under various loads, such as statistical off hook in conjunction with 100% penetration, 100% ringing under 100% penetration, etc. The results of this modeling are then used to call to the designer's attention plant segments which present unusual or poorly balanced powering designs, thus increasing the margin of safety at sub-100% penetration power system deployment levels.

Penetration Distribution between Power Source Service Areas

Perhaps the most difficult design problem is posed by the relative penetration success of one power source service area with respect to another. The small sample sizes offered by these service areas increase the probability of excess penetration in one area with respect to another. The nature of demographic effects in such small sample sizes is unknown, as is the amount of aberration from a normal statistical distribution due to factors such as the "word of mouth" popularity expected as customers try out the service in individual neighborhoods. Once the voltage starvation effects of lumpy distribution and traffic are addressed using the load modeling technique, then modular power sources can be deployed such that installed capacity can be increased on an as-needed basis without need to relocate these typically large and difficult to site power sources.

Conclusions

A number of important issues still exist surrounding CATV industry entry into the new services proposed for the information superhighway. There are answers for the majority of the technical issues, although many of them are currently very expensive. In the early deployment stages, many of the technical issues such as network powering and narrowcasting capacity must be over engineered to avoid the risk of market failures due to problems with system availability. Initial system deployment must be carefully monitored for margins, and the knowledge gained used to increase the efficiency of subsequent designs This approach will enable CATV systems to be competitive on a cost basis, and will allow the CATV industry to deploy a service equal to or better in nature, quality, and reliability compared to the competition.

The marketing side is probably even more hazy. There are many projects in progress to help clear the way (Time Warner's Full Service Network in Orlando). We believe the key to success is to keep an open mind and use all the tools available to build a flexible network–one which can be changed without taking a major detour on the information superhighway.

(1) Annual down-time analysis of selected broadband networks, by: Walt Strode, Director, Quality assurance, Phillips Broadband Networks, Inc.