584

# The Case for Residential Broadband Broadband Telecommunication Networks: Supply-Side Considerations

by Bruce L. Egan

Columbia Institute for Tele-Information
Graduate School of Business
Columbia University
809 Uris Hall
New York, NY 10027
(212)854-4222

DRAFT OCTOBER 1991 FOR COMMENT ONLY

# THE CASE FOR RESIDENTIAL BROADBAND TELECOMMUNICATION NETWORKS: SUPPLY-SIDE CONSIDERATIONS

Bruce L. Egan

## 2.0 Introduction

When demand is uncertain and, in any event, significantly lags network construction, the decision to invest in capital intensive construction projects like fixed "wireline" communication networks, whether for initial investment, upgrade or enhancement, is an extremely difficult one. This is especially true of telecommunications relative to other capital intensive industries (e.g. autos, petrochemicals, etc.) because many telecommunication services are "public" in the sense that demand directly depends on others also being hooked up to the network; therefore until the network itself is widely deployed, demand cannot take off.

Demand uncertainties notwithstanding, there are some advantages to public communication network investments compared to other capital intensive industries. Multi-service communication network firms feature production processes characterized by very high joint and common costs.

Telephone network operators are somewhat unique among capital intensive firms in that even though capital assets are fixed and immobile ("sunk") they are also relatively widely dispersed geographically in the network. In many situations local subscriber distribution plant comprises almost half, or even more, of total network investment and this provides opportunities for flexible technology adoption strategies. In other capital intensive industries, such as auto, steel, and energy production, adoption of a new technological paradigm involves major lump sum investments for large centralized production facilities. This contrasts with telecommunications for which the spatial distribution of network nodes and transmission facilities is relatively decentralized, allowing for selective upgrading and modernizing of facilities without major production interruptions. However, the slower the rate of network technology adoption in response to such fundamental changes as substituting analog copper and coaxial cable with digital fiber optics, the more it will raise the cost of "interworking" the two technologies during the transition phase. Nevertheless, it is useful from a capital budgeting perspective to have the flexibility which relatively small and widely dispersed facilities provide.

It is much easier and less expensive to alter, postpone, or cancel a telecommunication network construction project in response to market conditions than it is to do so for, say, a nuclear power plant. The primary reason is that portions of the network are useful for providing advanced communication services to customers in a certain geographic area without having to make them available everywhere. It is not necessary to have the entire network converted to be able to provide new service(s). New telecommunication services are often gradually phased in as network functionality becomes available to subscribers, though, from a demand perspective, it would be preferable to offer new communication services to everyone at the same time.

The risk associated with future demand is less for telephone companies than other capital intensive firms because of much shorter lead times and greater flexibility in construction. Construction time horizons for telecommunication network facilities are only one to three years for trunk and switching equipment, much less than is often required for capacity additions or replacement in many other industries. Uncertainty is accordingly less likely to affect the overall decision to pursue adoption of new technology; the financial implications of reaching a "point of no return" in construction are less. "Half a network node" or trunk group -- in terms of fungible plant capacity -- is better than none at all, but half a nuclear power plant is not. This provides a certain amount of comfort for telephone company management that, should future cash flows fall short of expectations, heavy borrowing from external sources is not necessarily required at the risk of derailing overall investment strategy. The bottom line is that no investment costs are sunk until actually committed.[1]

There are many possible engineering tradeoffs in broadband network design and construction which serves to complicate "costing out" each physical network alternative in a business case analysis. Most important are the tradeoffs among fixed and variable network cost components.

---

[1] For a discussion of costing theory and application and an examination of the relationship between embedded investment and the marginal capacity investment decision see: Lester D. Taylor, "On the Measurement of Marginal Costs," unpublished draft, University of Arizona, 1988, and Richard D. Emmerson, "The Theoretical Foundation of Incremental Network Costs," unpublished draft, Del Mar, CA 1991.

For example, two classic alternatives for capacity additions are to lay more fibers in an initial cable installation, or to plan for increases down the road by adding more electronic and photonic equipment as needed, thereby reducing up-front fixed investment in favor of future incremental investment in electronic devices. Such considerations alter the mix of fixed, sunk, incremental, avoidable, and variable costs over the planning horizon for any given network architecture. In turn, the regulatory cost allocations of telephone companies are affected since (mostly fixed) "Non Traffic Sensitive" (NTS) costs (e.g. fiber optic trunk cable) are allocated to state and interstate regulatory jurisdictions in different ways than "Traffic Sensitive" (TS) costs for electronic devices. Even in the case of unregulated cable television firms, such fixed/variable cost tradeoffs can alter pricing and capital recovery strategies prospectively, thus impacting the demand side of a business case.

The embedded base of network assets may also impact marginal investment decisions. Any given mix of embedded fixed and variable network facilities costs alters the decision parameters for future capacity additions, even though, in theory at least, after the embedded base of fixed costs were incurred they became "sunk" and non-avoidable (irrelevant) for future decisions (or future business case analyses). The past selection of network technology and architecture potentially can (and likely does) forever affect future marginal technology and capacity decisions.[2]

It is very important for successful strategic planning to anticipate impacts of current business decisions, such as choosing the next generation network architecture, on future decisions. In a

---

[2] Ref. Taylor, *supra*, note 1.

world of rapidly changing technology it is important to not simply adopt the least expensive short-run network architecture alternative especially if it is potentially *not* robust to future demand and technology changes which are anticipated in the planning process. In addition one must also consider how robust current investment decisions are to unanticipated demand changes. In the case of residential broadband networks, the unknown factors of new digital "wireless loop" technology (sometimes referred to as "micro-cellular" Personal Communication Networks or PCNs) and satellite technology may come into play and prematurely obsolete the land-based wireline loops. In fact, another fledgling communications technology still in the laboratory stage uses very low power wireless digital lightwaves for regular voice telecommunication.[3] No doubt other new alternatives for local telecommunication will appear on the scene. It would be important to avoid the potentially large financial mistake of deployment of dedicated fiber optic subscriber loops if indeed alternative technologies are around the corner which can provide similar service at a lower price.

Another important strategic consideration on the supply side of the broadband equation is to accurately identify the life-cycle stage of each customer service which is contemplated. Forecasts of demand growth and construction of network capacity requirements must be consistent with the place on the "S"-shaped life-cycle curve for each service. This obviously can affect the target for capital recovery or "pay back" period. For example, even though many entertainment video services represent a brand new growth business for telephone companies, they are well along

---

[3] "Pocket Phones Use Light to Keep Off Airwaves," The Wall Street Journal, Tuesday, August 13, 1991, p. B1.

in their respective life cycles and full market penetration may be around the corner. Growth in traditional mobile cellular service is also starting to slow. Thus, investment strategies for both network hardware and software must be geared toward capturing new customer service markets which are early in their growth phase.

Currently there are only two major players anticipated to have a significant role in the future game of network deployment for advanced two-way residential broadband communication networks, cable and local telephone companies. On the other hand, as might be expected, there are a host of potential players in the business broadband communications market, including cable and telephone companies, private satellite and radio network vendors, fiber-optic Local Area Networks (LANs), Wide Area Networks (WANs), and Metropolitan Area Networks (MANs). Due to relatively early demand drivers, such as those required for high resolution imaging to support health care, high speed computing, Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), and many other business applications, the development of the market for business broadband services will proceed quite differently than that for residential services. This is certainly going to be the case if public policies and regulations continue to force segmentation of the network market by restricting joint financial arrangements between major players, while emphasizing a market approach to private communication network development among niche network providers.[4] It will be less so if government authorities promote an infrastructure approach to broadband network technology

---

[4] Egan discusses network fragmentation trends at length throughout his book, see Egan, *supra*, Section 1, note 1.

deployment.[5] In the latter case, residential access to advanced communication networks need not significantly lag business subscriber access. Indeed, unless an infrastructure approach is taken, where government authorities promote early retirement of the old technology, it is not clear that residential broadband networks would be widely deployed before several decades have passed due to the long-lived embedded base of traditional copper phone lines.

## 2.1 Residential Broadband Network Evolution

No one knows what the socially optimal path for residential broadband network technology adoption is; predictions to date vary significantly, from one or two decades to perhaps never. Whatever the predictions, business decisions must be made in both public and private sectors as to what the next step will be. The world does not stand still; telephone and cable companies have to continue to upgrade their networks both to achieve network efficiency and to compete in the near term for new and advanced communication services. Furthermore, from the perspective of the nation as a whole, our performance for domestic economic and social productivity and international competitiveness may not allow us the luxury of simply waiting for the existing base of public telephone network technology to physically wear out before replacing it with a broadband alternative.

Making wise decisions regarding how to proceed to upgrade residential networks is complicated by the fact that reliable cost data for rapidly changing technologies like digital fiber optics and

---

[5] For some discussion of the distinctions between the two approaches see the introduction in Elton ed. *supra*, Section 1, note 5 and the article by Egan on pps. 179-192.

radio is scarce or even nonexistent. While we do have a reasonable level of knowledge regarding the costs of next generation cable and telephone networks, we have very little on second and third generations of network technology.[6] Thus, the overriding concern for private and public network planning is that we *not* embark on a short-run path of technology adoption that would not be at least roughly consistent with long-run choice(s) that promote social efficiency (i.e. those options that may achieve the greatest net gains to society in general). Clearly, not knowing what the future holds for new technologies, makes the selection among next generation network investment alternatives a difficult one, however there may be some short-run alternatives which are robust to unanticipated future changes in both supply and demand conditions.

Based on the cost and demand data available as of this writing, the remainder of this section discusses, in general terms, short-run alternatives for upgrading local networks with an eye toward examining their compatibility with a long-run vision for an efficient and highly functional two-way real time broadband communication network infrastructure. Before we can do that we need to identify what the future network functionality would (or should) be.

Many researchers foresee network technology ultimately evolving to a futuristic general purpose digital communications network featuring terrabit per second signal speeds in the core switching/transmission network, and gigabit per second signal speeds on subscriber access lines. Such a network would be able to effectively provide for all potential residential communication

---

[6] Reed and Sirbu state that it is just too early to tell what the ultimate path of technology adoption will (or should) be in Elton ed., *supra*, Section 1, note 5.

services demand. Unfortunately, even the most recent research yields two fundamentally different options for achieving this long-run vision, a very high-speed "active star" switched network, and an ultra high-speed "passive bus" or ring network.[7]

While there is virtually no production cost data for network facilities used in these futuristic networks, it remains imperative that we begin to examine the long-run viability of next generation alternatives. Along the way there are some architectural features to look for which may be used as guideposts for evaluating the relative difficulty of upgrading the short-run technological alternatives toward the combined long-run network objectives of high functionality and least cost. For example, in the case of a star network topology, centralized switching costs and transmission link costs are relatively higher than in a passive bus or ring architecture which features more decentralized routing/access nodes and less physical transmission facilities due to increased sharing. Thus, the initial choice of next generation local network architecture, be it passive/active, bus/star, or some combination of these, has implications for the relative costs of type of upgrade.[8]

---

[7] For a discussion of these two visions of futuristic broadband networks see "Adding Lanes to Data Highways," The New York Times, July 24, 1991, p. D1.

[8] For example, Reed and Sirbu make the point that it may be a much more expensive migration path if next generation technology favors local access architectures using Passive Optical Network (PONs) when the "correct" long-run architecture favors a switched star configuration, see their article in Elton ed., *supra* at note 5, Section 1. In his new book, Reed provides the most comprehensive set of cost data and analysis on network evolution issues and the complexities of choosing least cost short-run alternatives that may not be consistent with the preferred long run network architecture, see David P. Reed, *An Engineering and Economic Analysis of Residential Fiber Optic Networks*, Artech House, Norwood, MA, November 1991.

In a recent investigation of the costs of evolving networks Reed identifies several specific issues: "all fiber active double star (architectures), while preferred for network functionality offered and upgradability for new services is very expensive at about $3,000 per home passed due to high device and component costs. Hybrid architectures can be a half of that;" and "one problem is that passive star architectures are much cheaper for distributed (one-way) video, but not to upgrade to switched video. For integrated narrowband and broadband service, hybrid double star and bus passive architectures have future costs of $1,242 and $1,222 per home passed respectively, while future costs of all fiber active double star is about $1,684, even though it is only $289 over its narrowband all fiber counterpart." Reed continues in his analysis of the fully switched alternative: "the active double star topology preinstalls enough capacity in the distribution network to carry an integrated mix of narrowband and broadband servcies without the need for additional capacity.... Curiously, the all-fiber passive double star network is now the highest cost alternative."

Regarding an optimal deployment strategy, Reed states, "Clearly, the degree to which the upgrade to broadband services uses the existing plant is an important component of network evolution, the closer the upgrade cost approaches the total incremental cost, the more desirable the investment strategy." Of course, based on Reed's own analysis, it is not reasonable to assume that network planning could be so accurate that total upgrade costs would approach total incremental costs, due to the fact that the long path of technology adoption invloves several generations of network facilities where unique short-run considerations may dominate.

Interestingly, based on Reed's data, if we had the luxury of starting from scratch in constructing all fiber residential broadband networks, the active (switched) and passive alternatives are not that much different in terms of total costs. The problem is that we are not starting from scratch and there will likely be a substantial total cost penalty as a result. Such is the nature of dynamics of technology adoption when investment in network capacity is long lived and comes in large physical lumps.

## The long term vision

For telephone network operators in the US, the prevailing view of the preferred long-run network architecture is a switched star using fast packet switching and digital fiber optic transmission lines.[9] Many researchers are very strong proponents of the switched star broadband architecture based on perceived demand and network functionality requirements. For example a recent draft report by Fisher and Melmed prepared for the National Science Foundation stresses the need for a fully switched network to assure maximum functionality and access to all types of information. In addition, a recent paper by Geller makes a compelling First Amendment argument for fully switched broadband networks as maximizing the potential for diversity in access to all types of information.[10]

---

[9] See for example the survey of FTTH broadband network architectures in Egan *supra*, Section 1, note 1, chapter 7, and the discussion by Reed and Sirbu in Elton ed., *supra*, Section 1, note 5.

[10] See Francis Dummer Fisher and Arthur Melmed, "Towards a National Information Infrastructure of Education," Center for Educational Technology and Economic Productivity, New York University, draft, June 10, 1991; and Henry Geller, "Fiber Optics: An Opportunity for a New Policy," A Report of the Annenberg Washington Program, Communication Policy Studies, Northwestern University, draft, August 1991.

The name for the new broadband network system is called Synchronous Optical NETwor (SONET) and many of the technical standards for it have already been worked out,[11] however another view is emerging based on the phenomenal potential capacity of fiber-optic transmissio lines, which may still use fast packet switching, but in a passive, more intensively shared arrangement.[12] Technological development of the latter passive broadband option may be a ful decade behind the SONET switched star network plan currently favored by telephone utilities.

At this early stage it is very difficult indeed to select between these two fundamentally differen long-range alternatives. Suffice it to say that the active switched broadband network option i the lead horse in the broadband race, if for no other reason that the engineering momentum tends to favor the relatively well known switched telecommunication network alternative. Thus, at the risk of analytical error, the following evaluation of short-run alternatives to meet long-run objectives will favor the switched broadband architecture. To do otherwise would make it virtually impossible to favor any given short-run alternative if their long-run counterparts (e.g. switched star vs. passive bus) are so fundamentally different. This distinction clearly has implications for the current race between cable and telephone network operators to upgrade their networks to become a "full service" supplier in the Information Age. Once more is known about the relatively new passive two-way broadband network architectures, this issue will have to be revisited.

---

[11] For a nontechnical discussion of SONET see Egan, *supra*, Section 1, note 1, pps. 32-34; for a more detailed discussion see Reed, *supra*, note 8.

[12] Ref. New York Times article, *supra*, note 7.

As will be demonstrated below, cable operators have a significant short-run absolute cos advantage over telephone companies in achieving a local network capable of simultaneousl providing functionality for two-way narrowband and one-way broadband (downstream communications. But this cost advantage derives mostly from upgrading cable firms' curren passive video distribution network to provide for two-way voice, data, and information services Upgrading to a fully switched broadband capability remains a very costly proposition, even fo cable firms, in the range of the per subscriber costs of upgrading telephone networks for simila capability. Thus, based on the available evidence, there is no significant long-run cost advantag to either cable or telephone companies to achieve advanced two-way switched broadban functionality. In fact, if the long-term vision is a switched one, the ultimate cost advantage may lie with telephone companies since they are already operating switched networks. Reed and Sirb have suggested that the costs of achieving switched broadband capability may be substantially higher if a network operator is starting with a hybrid (fiber/metallic) passive distribution network rather than an active switched one. Even so however, this does not necessarily give the telephone company a great advantage since the current base of digital network switches, featuring relatively low real time signal throughput, are themselves not capable of supporting the futuristic network speeds that are contemplated, and currently extend only to about 35% of US households.

## Residential Local Network Architectures and Costs

There are a number of possibilities for designing residential local network architectures. There are vendor systems which utilize "bus," "star," "ring," and "tree-and-branch" architectures and hybrid fiber-optic/metallic cable systems; there are even some hybrid cable/radio systems on t drawing board. Systems may feature "active" and "passive" devices and components and variou combinations of both. It is difficult to directly compare many vendor system architectures an costs; they feature different combinations of fixed and variable cost components and diffe greatly in their initial functionality and "upgradeability" for adding features and functions.

Thus, the selection of any particular system or architecture will depend on the assumptions o the types and levels of customer service demand which, in turn determines the minimum an maximum functionality and capacity of the particular system anticipated by the network supplie facing the investment decision. Specification of such network capacity engineering requirement are beyond the scope of this exercise. In their research, Reed, Johnson, Sirbu and others hav made some assumptions of prospective demand levels, but to this author's knowledge, no system capacity parameters have been estimated which would even begin to satisfy the potential demand for the plethora of possible new service applications. However there are some basic supply-side "rules-of-thumb" that appear from the available cost data for various types of systems.[13] While the functionality of any given access line architecture determines *which* customer services may be supported (e.g. voice, data, video, etc.), it is much more difficult to determine "how much" peak service demand is possible, or even the quality of the service (e.g. very high resolution motion video vs. low resolution imaging for the same demand application).[14]

---

[13] For cost data surveyed see: Egan, *supra*, Section 1, note 1, chapter 7, and references therein.

[14] The answer to which services a given system could nominally support is actually quite straightforward once the network functionality is known. More difficult questions of quality and

## Construction Cost Benchmarks

The most advanced network architectures feature two-way, on-demand, broadban communication functionality and may support the entire range of residential services which ar contemplated, including real-time two-way video telephony. These architectures have very hig deployment costs, in the range of $1,500 to $15,000 per residential subscriber. This represent the total installed cost of the first access line. With about a hundred million subscribers in th U.S., this implies a total cost of residential broadband networks in the range of $100-$1,50 billion for universal deployment. Deployment costs are substantial whether for telephon companies, cable companies or others. The fiber cable itself is relatively inexpensive. The tw main incremental cost factors are the initial engineering and construction costs for laying fibe cable all they way to the subscriber premises, and the costs of opto-electronic components an devices required to allow existing Customer Premise Equipment (CPE) to interface with, and operate on, the photonic distribution network.

Cable companies, which use passive transmission ("bus" or non-switched) in their subscriber loop architectures could pursue a residential broadband construction program which would cost much less than a traditional telephone company switched loop architecture. However, to provide network functionality equivalent to telephone companies, cable technology deployment costs would still be substantial, in the lower range of cost estimates for telephone company supplied

---

peak load involve many complex technical tradeoffs of compression, multiplexing, buffers, memory, etc. While it may be true that at any given instant in time physical capacity of an access line is fixed, it is also true that system software may be altered to change the information throughput per unit of physical capacity. Such complex issues require further research.

access lines. It is important to note that the cost estimates at the lower end of the range providec are "forward looking," meaning they are estimates assuming mass deployment using productior equipment costs. Those cost estimates at the high end of the range are usually based on limitec deployment and some prototype equipment and service arrangements.

### Fiber-To-The-Home (FTTH)

A survey of existing engineering cost estimates for telephone company local FTTH networks yields a very wide range of per subscriber costs depending on the system architecture. functionality and demand assumptions. None of the cost estimates presented below include CPE or other types of costs incurred on, or inside, of a customer's premises. At this early stage, none of the cost estimates can be dismissed out of hand since the estimates are extremely sensitive to assumptions regarding levels of deployment, both in terms of penetration (the ratio of actual subscriber connections to total potential subscriber connections), and prospective cost declines for devices and components. The most oft-quoted numbers are in the range of $1,500-$3,000 per subscriber. There is no such broad survey of FTTH cost estimates for cable television companies, however the range of costs which are available include many systems using passive delivery of video on a fiber optic bus, typical of cable delivery systems. The cable industry has not shown any significant interest in FTTH since they view their broadband coaxial cable subscriber loops adequate for two-way residential broadband service when fiber optics is deployed in their trunk networks.

As fiber optic device and component costs fall, and progress is made in optical/electronic interface units, POTS-only FTTH systems may be efficiently upgraded to provide advanced two-way services. Many vendors of FTTH systems and equipment have announced migration strategies for subscriber loop plant from basic to enhanced functionality, some ultimately providing for high quality two-way real time broadband service.

Figure 2.1 shows a stylized FTTH access line architecture consistent with today's state-of-the-art telephone loop plant design. The estimated per subscriber cost of a POTS fiber access line is about $3,000 for this stylized suburban residence network service configuration which could exist in the early 1990s, which may be considered a "target" subscriber due to the relatively short loop length. This architecture features a Digital Loop Carrier (DLC) at the Serving Area Interface (SAI). Notice that, for this particular loop architecture, the feeder portion of per subscriber costs is only about $100 or about 3% of the total costs of subscriber loop plant (two-thirds) and associated electronics (about one-third of the total per subscriber costs).

### Fiber Backbone Networks

Both telephone companies and cable companies can deploy fiber backbone networks at a small fraction of the cost of FTTH, because fiber is exceptionally well suited for shared (non-dedicated) subscriber plant and will likely be preferred in new construction for trunk and feeder facilities based on cost savings alone.

Figure 2.2 is a stylized view of a fiber backbone trunk network for cable companies. For a telephone company fiber backbone, refer to Figure 2.1, assuming that only the central office to digital remote terminal portion of the access line would be fiber, and the remainder of the subscriber loop would be copper. Notice the cable network fiber optic trunk backbone may be deployed for an average incremental cost of about $36 per household.

Given the available data, either telephone companies or cable companies can upgrade the local distribution networks with a fiber optic backbone for about $100 per subscriber, or even less in the case of cable companies. This, however, is where the good news ends for telephone companies. Even though cable or telephone company fiber backbone costs are about the same per residential subscriber, the difference in quality, reliability, and future functionality leaves no comparison -- cable companies win hands down. A telephone company fiber backbone, while perhaps more reliable and of higher quality from a network engineering and maintenance perspective, holds virtually no service advantage for customers; subscribers still only get two-way narrowband telecommunications due to the limitation of the existing copper loops.

### Fiber-To-The-Curb (FTTC)

There is a big difference in the cost of fiber backbone networks and FTTC, whether for cable or telephone companies. In fact, most available estimates of per subscriber costs of telephone company FTTC for two-way broadband networks is over ten times that of per subscriber fiber backbone costs, in the range of $1,000-$1,500, though some newer vendor systems do claim lower costs for mass deployment. Some cable operators have already deployed fiber-optic trunk networks for only about $30 per subscriber in early applications; extending the cable network fiber trunks out farther in the feeder portion of cable plant can add substantially to this cost (about $150-$250 per subscriber). Even so, it should be noted that fiber optic cable trunk and feeder networks generally do not imply extension of the fiber cable as far downstream in the network to the subscriber as is implied by telephone company FTTC. The typical telephone company fiber/copper "node" or pedestal in FTTC systems may be placed all the way out to the point of existing copper drop lines. This point, called the "pedestal" only serves about 4-16 homes. In the case of cable television, current hybrid network designs allow the fiber/coax "node" to serve about 500 homes. Thus, the functionality of telephone company FTTC systems and the cable hybrid networks may be quite different, making per subscriber costs difficult to compare.

FTTC systems are only about one-third to one-half the per subscriber costs of FTTH and, in the case of telephone companies at least, FTTC may offer a significant increase in network functionality for subscribers, while fiber feeder backbones do not. As a result, there is substantial interest in telephone company deployment of FTTC. A host of telephone company FTTC network architectures have only recently been proposed by a number of vendors and others are still in the laboratory development stage.

Reliable cost data are sparse, although some major industry sources put the total per subscriber costs of FTTC nearly equal to the costs of new residential copper access lines. This is not surprising considering the cost advantages of fiber in shared network facilities. It is the dedicated subscriber portion of the loop that makes FTTH so expensive. FTTC allows for sharing of opto-electronic network interface devices and components among many subscribers.

Telephone companies must consider deployment of FTTC since fiber feeder backbones simply do not offer much in terms of value-added for customers. With FTTC, a high quality broadband capability may be achieved by interconnecting to coaxial cable for the final subscriber loop segment. Initially, only POTS and one-way video will be likely in telephone company FTTC networks, but this is the minimum configuration necessary to match the potential functionality of advanced two-way cable television networks.[15] In fact, as of this writing, almost all major Local Exchange Carriers (LECs) have endorsed a policy of FTTC instead of FTTH for their next generation of "broadband capable" subscriber loop plant.

Cable companies as well need to deploy FTTC to be able to match the potential subscriber network functionality of telephone company FTTC. However, it is a bit easier for cable companies since the critical (and relatively expensive) last network segment -- the subscriber connection -- is already broadband coaxial cable. There may be cost effective ways to connect cable fiber optic backbones to telephone company switched network facilities to achieve a high quality two-way telecommunication capability. The cost data available to date, however, indicates that cable company FTTC deployment costs could also be quite high if two-way digital telecommunication functionality is required -- $1,000 per subscriber or more. One such system appears in **Figure** 2.3.

There are two potentially important shortfalls in many of the telephone and cable company

---

[15] It is not that they wouldn't rather provide real-time two-way broadband functionality, only that the costs of doing so are so high that this capability will be deferred until the second (or third) generation of local networks is contemplated.

FTTC systems, a lack of switching and real-time interactivity. Most vendor FTTC systems being considered for the next generation of residential broadband networks do not use switching for all network services due to the relatively high up-front costs this implies. The result is a more passive network architecture for one-way video distribution which is limited in functionality compared to an all-switched video system. The bandwidth offered on the coaxial cable portion of the network in FTTC systems may not be able to support real-time subscriber interaction with the communication media especially in an integrated environment. This may seriously cut down the demand for new service applications described in the next section.

### Cost of Power

Unlike copper, fiber cable cannot carry electrical power to run network components. Therefore, the cost of power in a fiber network can represent a significant portion of total investment, at least relative to today's cost for power. Network performance requirements call for continuous powering of the network and decentralized electronics require direct connection to local commercial AC power or a separate (or integrated) copper network. This can significantly raise the costs and compromise the original intent to switch from an electric transmission medium (copper) to an all dielectric one (fiber). The problem of powering has forced many vendor FTTH and FTTC systems to require the use of fiber/copper hybrid distribution cable. Requirements for backup (e.g. battery) power, which must be available in case of commercial power failure also increases costs. In particular, the optical network interface (ONI) must have continuous power, regardless of its position within the network. Cable television companies may be able to use their existing coaxial cable network facilities to support powering requirements in a hybrid environment. Several studies have calculated the cost of power at different locations within the network.[16]

## Cost Summary

In summary, a survey of the available data yield some representative average cost relationships:[17]

- Current (early 1990s) cost estimates for FTTC systems providing for two-way narrowband digital services (ISDN) and one-way distributive video service are about $1,500 per subscriber while FTTH systems average $3,000 to $4,000. These are costs for Passive Optical Networks (PONs). A fully switched system would cost significantly more or about $1,000 per subscriber.

- The future cost (late 1990's) is substantially reduced due to anticipated declines in unit costs for devices, components, switching and transmission, to about $1,200 for FTTC and about $1,500 to $2,000 for FTTH.

- For advanced switched FTTC and FTTH broadband systems, the future (late 1990s) costs are about $500 higher. The problem is that once PONs are installed for the next generation network upgrade, a fully switched system upgrade will not utilize much of the old investment in the

---

[16] For some cost data on network powering see Johnson and Reed, *supra*, Section 1, note 3, Table H1 p. 94, and references therein; for a discussion of the technical considerations for powering fiber-optic network systems see article by George T. Hawley, "Break on Through to the Other Side," Telephony, January 14, 1990.

[17] For more detail see the cost survey in the NRRI report, *supra*, note 13.

PON.[18] Some inefficiencies in the technology adoption path will be inevitable considering that the only alternative is to wait for fully switched systems costs to fall toward those of PONs. It is not known if or when this would occur.

- When considering the current cost per subscriber for FTTH systems that provide both narrowband and broadband service:
  - electronics usually represent one-third to one-half of the total cost of the subscriber loop plant
  - feeder represents approximately one-tenth of the total cost
  - loop and distribution represent approximately one-half of total cost

- The cost per subscriber for narrowband FTTC systems is usually about $1,000 less than FTTH broadband systems

- Considering the cost per subscriber for broadband FTTC systems:
  - total cost is usually one-third to one-half of FTTH total cost
  - electronics represents one-half to three-quarters of total cost
  - coaxial drop from curb (pedestal) is about $150-200, twisted pair copper drop from curb (pedestal) is usually about $75-$150

---

[18] Much of the electronics, muxes, optical splitters, etc. will not be required for the fully switched systems.

- Aerial installations cost one-third to one-half of underground installations.

**Mapping Communication Services to Network Architecture and Functionality**

Not only are there many alternative network architectures and technologies which provide for a given level of service "functionality" for the end user, but network functionality itself features many dimensions when considering the range of possibilities for final services demand. It is not enough to simply state that a given integrated local network architecture can support one-way broadband and two-way narrowband, or even two-way "interactive" broadband service because, at the most fundamental engineering level, all network designs will at some point exhibit many different capacity constraints, each one ultimately dependent on the nature and form of the actual usage ("traffic").

There are a host of considerations which make it difficult to arrive at a "least common denominator" for optimizing network functionality in a broadband environment. For reasons of cost economies of scale, a fixed network provider will have to select a single broadband loop architecture in any given local service area. But in the future world of "personalized" flexible digital networks featuring a vast array of potential end user services, is there going to be any such thing as an "average" household or business in terms of originating and terminating local traffic characteristics? This proposition is doubtful, nevertheless, for capital budgeting purposes, some average loop architecture, featuring some average level of capacity and functionality, will have to be estimated by the fixed network provider.

A simple example will illustrate the point; just because a subscriber's (household) integrated network access line allows for enough "engineered" bandwidth capable of supporting advanced video service, like high resolution on-demand video, does not mean it will always provide such functionality in practice. What if the same household wanted to simultaneously use the "phone line" for any number of other applications, like learning, working, shopping at home, or even just to send faxes or perhaps a voice, data or video telephone call? Would we demand the viewer of the movie at the moment, or the player of the interactive video game, quit while the alternative application is used, or perhaps this household has special CPE to allow them to perform all the services demanded at the moment with no (perceptable) inconvenience to anyone? Wasn't the whole point of integration to allow for the potential of multimedia and interactive communications across many users? What is the "optimal" peak capacity for the proverbial "household," and where is the line to be drawn on the "right" number of services and bandwidth requirements for a typical household.

For example, one uncompressed high resolution video communication channel may require transmission speeds of 150 Mbs, enough to fill the current CCITT international standard for broadband service, precluding the simultanous transmission of alternative voice or data communications. Of course, the signal may be compressed (at some expense) to much less bandwidth, 10 Mbs or so, but there are still going to be other capacity constraints in the network to deal with. Take the case of a switched network with rapid channel changes as customers "flip" the video receiver channel selecter, now the capacity constraint will be in switching instead of transmission. This causes order of magnitude increases in activity at the network node providing the video signals. It should be noted that the very availability of more channels potentially will aggravate this problem as subscribers exercise their option to browse channels. Take the case of a heavy surge of customer querys to an intelligent network node database storage area, this also would cause a potential peak capacity constraint only now it is in the network processing function.

Of course the characteristics of the actual network traffic in space and time dimensions cannot be known ex-ante because demand significantly lags the construction of the broadband network itself. This is where the critical task of accurately mapping potential services demand to alternative network architectures and their physical network hardware and software features and capabilities comes in. If much of the expenditures for network infrastructure investment is going to come from the general body of telephone service subscribers, the most likely scenario, it will be that much more important to match network functionality with subscriber demand. It is incumbent on the research community to carefully examine this problem in order to provide some guidance for optimizing over long-run investment alternatives.

Unfortunately, as will be discussed below, we are far from a satisfactory determination of potential traffic characteristics; in fact we are just beginning to understand the functionality of the new technologies in practice and how best to combine them. At this early stage it appears that the economic and engineering tradeoffs among alternative network architectures are innumerable, therefore it is imperative that we tackle the daunting task of mapping services demand to architecture to point us in the right direction.

One might wonder why the difficult issues of matching the optimal network access line architectures with potential services demand was not such a problem in the past. The reason is that digital fiber optic technology constitutes a paradigm shift in the telecommunications industry by enabling a subscriber to integrate all service demand on a single access line. In the past, any substantial change in service demand simply required another access line. For example, in a non-integrated environment, if a subscriber wanted to have data service they would order it from the telephone company and a dedicated access line was provisioned for it. There simply was no sharing of access lines and therefore they were essentially a non-blocking network facility, the line was either "in use" or not. Of course there still were many peak capacity constraints in the non-integrated environment, but they were all in the shared network nodes and trunks. Fiber optic access lines, as a medium for service integration, brings to the fore the issue of peak capacity requirements. For the first time in telecommunications network history, the dedicated subscriber access line itself represents a potentially serious peak capacity constraint.

### Traffic Characteristics

What will be the nature of telecommunications traffic for residential and business consumers of the future? The answer may depend on current trends and possibilities for new services like those discussed in Section 4, or perhaps may be totally different as predicted by some industry visionaries.

There do appear to be some obvious changes to consider from traffic characteristics of the past. At the least we can expect that machine-to-machine and human-to-machine communications will grow very rapidly relative to today.[19] We also can expect that distributed digital signal processing will become dominant as remote computing and intelligence becomes relatively more cost effective and as components and devices continue to decrease in size and price.

There are many other areas we know very little about, but which are surely critical determinants of the future characteristics of network traffic. For example, it is well known that a vast majority of network costs are capacity sensitive, as opposed to "usage" sensitive; the latter refers to frequency of transmission of information as opposed to peak utilization (in terms of bit processing) of the former. This is especially true for fast packet switching of future broadband networks. From the perspective of the end user of communication services the situation is even more complicated. Sophisticated CPE may tolerate a different (lower) level of functionality from the shared network itself and therefore functionality for one user is different from another not equipped with similar sophisticated CPE. There are any number of possibilities for the use of CPE or local network devices for digital signal processing for compression, memory, storage, retrieval, buffers, etc., all of which affect the level of end user functionality.

The purpose of this discussion is not to be fatalistic but rather to emphasize the complexity of the issues and problems of service mapping. Surely there are so many simultaneous factors to account for in predicting traffic characteristics that the "dimensionality" of the optimization

---

[19] Shimisaki refers to machine data communications as "structured" and, "natural" (including human) communication as partly "structured" and partly "unstructured." See, for example, Nobuhiko Shimisaki, "Unified Alignment of ISDN-Relevant Information Communications Services/Applications Through a Cubic Framework," International Journal of Satellite Communications, vol. 9, 1991.

problem would seem to require a supercomputer to solve it, and even then the result is a probabilistic (risky) one. Thus, perhaps the real research challenge is how to reduce the number of dimensions to simplify the analysis. A heirarchical ordering of critical dimensions is a place to start.

### Service Mapping Dimensions

No attempt is made to list all of the possible services, applications or communication activities. Rather, broad categories of activities will be discussed.[20] The following is a list, not necessarily in the correct order, of the relevant dimensions of the service "mapping" problem. The perspective is that of the residential end user household of potential communication services in a broadband environment:

1. User type (machine/human)
2. Application type (fixed location, mobile, voice, data, text, image, video, multimedia)
3. Activity type (entertainment, learning, working, health care, traveling, shopping, browsing, reading, listening, day care, transactions services, etc.)
4. Traffic characteristics, depending on specific application (moving in space (portable), bursty,[21] continuous, uniform, permanent, temporary, dynamic, static/still, one-way, two-way

---

[20] For some examples of specific communication activities and services refer to Section 4 and the references therein.

[21] This one is particularly interesting since it may be an important peak capacity constraint, even for video services if they are provided on switched networks. Even though video services are a classic example of a service optimized for "passive" (distributive) network architectures due to continuous transmissions, with new compression technology video becomes relatively "bursty", especially in videos featuring fast movements over large portions of the display screen. Slow moving and still scenes are ideal for compression and would cause large surges in traffic

(balanced/unbalanced), "interactive"

5. "Latency" requirements of the specific application/activity (real time, acceptable (perceptable) delay time)[22]

6. Level and speed of computing required for the application (as opposed to network transmission speeds; what level of network computing (e.g. signal processing) is required to turn the originating transmission into information useful to the application?[23]

7. Digital signal compression (from network or CPE)

8. Alternative system architectures for hardware (firmware) and software for a desired level of functionality of the network connection and CPE relative to the application/users demand for

---

whenever motion scenes appear. Advocates of fully switched star network loop architectures for broadband service must take note of the massive increases in processing requirements at the switch when end users change video channels a lot. This surely puts a large demand on switch capacity. Passive networks like cable television do not exhibit this problem.

[22] "Latency" refers to a critical feature of the human aspects of interactive service demand. For any given service application, latency identifies the acceptable, or at least tolerable, amount of time delay from the perspective of the human or machine "user." Digital signal processing techniques for compression, memory buffers and storage may allow the network to "satisfactorily" support a given service application without undue annoyance to the user when "raw" bandwidth capacity of the network connection (e.g. access line), or CPE may not. In other words, for many specific service applications, it may be possible to use very fast digital signal processing in the network or CPE devices to make potenially annoying response delays appear as real time communications. The latency issue was recently highlighted by Sirbu in a presentation made at a broadband seminar in Philadelphia, "Telecommunications, Information, Technology and Industry Change: From Here to Broadband ... and Beyond," Center for Communications and Information Science and Policy, University of Pennsylvania, September 5-6, 1991.

[23] There are various network processing requirements which may be triggered by end user transmissions, such as protocal conversions, database and network computing and translations, etc., and any given requirement for processing could occur at any level in the core network, from the fundamental (physical) network level to higher (applications) levels or anywhere in between.

throughput, peak capacity, buffer/storage requirements, dynamic bandwidth allocation, and digital signal processing features.

In theory, even after accounting for all these factors from an engineering perspective, the optimized network model must be incorporated into an economic optimization model where the fixed network provider specifies the decision time horizon for the investment (e.g. 10 or 20 years) and evaluates the dynamic net cash flows which are likely to arise from anticipated supply and demand conditions.

Obviously, there is no single network architecture that could optimize over all of the above dimensions in the face of uncertain demand, especially when the technology itself is so dynamic. An analogy comes to mind in the area of optimization of personal computer applications; system design experts will tell you that even when they are presented with a relatively simple computer program which runs on a PC, but one that is used to accomplish a specific task for a given customer, they are often able to optimize the PC hardare and software configuration to achieve an order of magnitude improvement in application processing time without even changing the basic physical hardware system processor chip. This is done by optimally configuring system and application-specific software with available RAM, memory, and internal speed to perform the task at hand. Compared to optimally designing a residential broadband network over a dynamic (unknown) mix of service applications the PC example seems a terribly simple one, yet systems experts spend many hours on them. Imagine the research requirements for sophisticated redundant systems like those of the space shuttle.

The recent research record provides further empirical support of the difficulty in mapping ex-ante service demand with broadband network optimization over the long term. Reed and Sirbu, Johnson and Reed, and Reed[24] all have evaluated alternative local network architectures for only a very limited and relatively well understood service mix, two-way narrowband digital service and one-way "on-demand" entertainment video service. These studies imposed very strict and "well behaved" demand patterns on per household peak usage levels at 1.5 hours a day for video and 64kbs for narrowband channels up to 144kps total two-way capacity (basic ISDN service) over a single broadband access line.[25] Even assuming that all households' television viewing habits were exactly the same and assuming such a limited service mix and network functionality to support it, these authors found that a number of physically distinct network architectures yielded unit costs that were very close to one another, and therefore clear chioces among them were difficult. The authors also generally agreed that the network cost model results were very sensitive to changes in demand assumptions regarding service penetration and peak capacity requirements. Furthermore, inclusion of many more advanced services into the analysis, especially two-way real time broadband service, would increase the complexity of the network optimization model substantially. In light of the research record to date, finding a parsimonious framework of anlysis may be the key to significant progress.

---

[24] Supra at note ____.

[25] Similar strict parameters were placed on the topology of the stylized "neighborhood" which was being equipped for broadband service. Johnson and Reed also looked at per household viewing levels lower than 1.5 hours up to 6 hours, but in each case, they assumed that all households were exactly alike.

## A Recommended Approach to the Ex-ante Service Mapping Problem

One may be tempted at this point in the discussion to simply give up on the complex optimization problem described above and instead take as the investment objective the deployment of the network technology and architecture that provides a given level of functionality, in terms of peak capacity "on demand" guaranteed bandwidth at the lowest unit cost per subscriber. This is the approach taken in the next section. In other words, basic network functionality is characterized by a given level of guaranteed on-demand capacity, and various system architectures may then be evaluated based on unit costs of available "working" capacity. While the approach can be criticized as not being "demand driven," there is not enough reliable demand or cost data available to drive a sophisticated optimizization model and, in any case, is well beyond the scope of the present exercise.

The suggested alternative "supply side" exercise is quite useful for planning purposes because if it is determined that the chosen bandwidth requirements may not be sufficient for some demand scenarios, then it is straightforward to increase the on-demand bandwidth requirements to a higher level, and subsequently "cost out" various alternative network architectures again. Sensitivity analysis over a whole range of peak on-demand capacity (bandwidth) levels is possible and various network architectures and technologies may be evaluated for each.

After such an exercise, various demand scenarios for a range of service mixes may be evaluated relative to each specific network architecture and corresponding functionality in terms of peak on-demand capacity identified in stage one to see if they are relatively more efficient from a cash flow perspective. There are at least two logical possibilities for matching potential service demand with the level of guaranteed on-demand access line capacity for each system which was costed out.

First, an actual field trial is possible and this is being actively pursued by the research consortium MCC in a project called First Cities. Fiber optic access lines will be widely deployed in a local residential area broadband network. The problem with this approach is obvious. It will be many years before CPE and other network devices enable consumers to use the network in novel ways for new service applications. Thus, in effect, new demand forecasts will end up being partially extrapolations of old demand trends.

The second approach would be a computer simulation model where service usage and network access for a "household" would be input to a given model network architecture like those costed out previously. Peak capacity constraints from various randomly selected service mixes would be isolated by the model, and each candidate network architecture would be subjected to the same computer generated service mix in the same space and time dimensions. This approach would allow for mapping services to the least cost network architecture for residential access lines. The advantage of the approach is clear. No significant pre-judging of the future service mix is imposed on the model and the cost of analyzing the whole problem is much lower than trying to optimize over all of the factors listed above. Of course it is the very same peak capacity constraints and network parameters listed previously that are driving the computer simulation network model, however the problems associated with identifying critical constraints and their effects on costs ex-ante are avoided because the simulation allows for an ex-post evaluation based on the computer generated "services."

## 2.2 Alternatives for Broadband Network Upgrades

Some recent research has provided a good description of likely public network evolution scenarios for both cable and telephone companies. A basic network model describing the network upgrade process appears in a recent report released by the National Regulatory Research Institute.[26] A much more detailed technical discussion along with highly disaggregated cost data appears in the recent research of Reed and Sirbu and Johnson and Reed.[27] There are numerous alternative local broadband network architectures and deployment scenarios to consider, each of which may feature different levels of unit costs and service functionality. For analytical convenience the following scenarios cover the likely range of short and long term network upgrades for both telephone and cable companies:

### Telephone Company Broadband Network Upgrades

1. Short term - Local Exchange Carrier (LEC) Fiber-To-The-Curb (FTTC) network
2. Long term - LEC Fiber-To-The-Home (FTTH) network

---

[26] For a basic framework and discussion of the "nuts and bolts" of upgrading narrowband telephone networks for one-way video service, and cable networks for two-way voice and data service, including illustrations of alternative loop architectures, see, "An Analysis of a Portion of the Cost of Converting a Local Telephone Utility Network into a Network Capable of Delivering Broadband and Cable Television Services to All Subscribers," National Regulatory Research Institute, Oct. 18, 1990.

[27] Johnson and Reed *supra*, Section 1, note 3; and Reed and Sirbu in Elton ed., *supra*, Section 1, note 5, and Reed *supra*, note 8.

**Cable Company Broadband Network Upgrades**

3. Short term - Cable hybrid fiber/coaxial cable network
4. Long term - Interactive broadband cable hybrid network

Depending on the alternative being considered, the investment path of technology adoption may be quite different. Alternatives 1 and 3 may be characterized as "next generation" but still introduce fundamentally new network capabilities for telephone companies and cable firms. Alternative 1 would, for the first time, allow telephone companies to provide simple cable television as well as advanced information services. Alternative 3 allows, for the first time, cable television company provision of two-way narrowband telecommunication services. Thus, from an end user perspective, the basic functionality of the two short run alternatives is roughly identical; both potentially will support two-way narrowband digital services and one-way broadband services such as high quality distributive video services.[28] Interactive information services and low speed imaging services will be obtained through narrowband digital capability.

---

[28] For two-way narrowband service, the initial capability would be a single channel capability which would support end user services up to about 56-64 Kbs. Full ISDN (144 Kbs) narrowband capability featuring 2 full circuit switched channels of 64 Kbs each and a 16 Kbs packet data channel could be provided for at fairly low additional cost. In both cases the use of the digital network access line will require new digital CPE or adaptive devices with codecs for analog to digital conversion. The initial bandwidth capacity of the distributive broadband channel would be at least 45 Mbs digital, or at least 6 Mhz analog (single NTSC television channel capability). Of course, in the case of the coaxial cable television network access line, the number of television channels recieved may be more than one per household, up to one per television reciever. Thus in order to match the functionality of cable networks it will become important for telephone company broadband network systems to expand access line speeds for distributive video services beyond 45 Mbs. In many early broadband network system designs, the distributive video signal will remain analog due to the lack of digital network video switches and digital video CPE.

A consumer's ability to use many enhanced communication services will hinge partly on the private availability of sophisticated network electronics (for digital signal processing) and CPE.

Relatively good network cost data are now available for evaluating the two short run network upgrade alternatives. However, even for these we lack good data on the cost of CPE (e.g. converters, adapters and terminals) which would allow a subscriber to utilize the increased functionality of the network for new services. At this early juncture, since the network functionality of the alternatives 1 and 3 is basically the same, we assume that the cost of advanced CPE for each would be also. Due to a lack of reliable demand forecasts for these network alternatives, it will not be possible in the cash flow analysis to follow to develop the demand side of the equation beyond assumptions about basic network functionality. Demand projections which do exist in the literature are usually based on known subscriber services such as traditional cable and telephone services as well as some anticipated information services like primitive (non-interactive) videotex services.

Even though the potential network functionality of alternatives 1 and 3 to fulfill service demand is similar (i.e. at the minimum both may support "Plain Old Telephone Service" (POTS) and "Plain Old Cable Service" (POCS)), it will is still possible to make preliminary judgements regarding the relative financial viability of each. Based only on their deployment costs there is enough data on these two network upgrade alternatives so that it is possible to make some meaningful comparisons of net (negative) cash flows. This is explained further in the Net Present Value (NPV) analysis that follows.

Alternatives 2 and 4 represent advanced versions of alternatives 1 and 3 respectively. They are advanced because both of these alternatives potentially feature the functionality required to support the entire range of two-way real time (interactive) broadband communication services which are currently anticipated. It is premature at this point to exactly specify the bandwidth capacity requirements of subscriber access lines. Current international standards call for a basic transmission rate of 150 Megabits per second (Mbs) and primary rate of 600 Mbs. While this seems large, gigabit per second (Gbs) access lines are contemplated in some scenarios. In fact, a cable system in Queens New York is already building a new hybrid fiber optic/coaxial cable network offering 1 Ghz capacity on subscriber access lines.[29] An upper bound for capacity to provide for all potential services is very hard to define. In the September 1991 issue of Scientific American several articles by leading experts in communications and computing discuss futuristic services such as "virtual reality" and moving (interactive) holograms which are said to potentially require terrabit network speeds!

The extent to which new subscriber services may ultimately become available on broadband networks depends on the type and cost of advanced network terminal equipment located on the subscriber premises. There is virtually no cost data for this. For the most part broadband digital CPE is still on the drawing board. While there are some preliminary forecasts of network costs for both long run alternatives 2 and 4 there are few, if any, demand forecasts for them in the literature. Most existing studies simply make some broad average assumptions about initial demand levels for one or a handfull of services and hypothetical growth rates to allow for

---

[29] See, Gary Kim, "Time-Warner is First With 1-Ghz Cable TV," Lightwave, May 1991.

sensitivity analysis. Such is the basic approach taken by Reed and Sirbu in their analysis of network upgrade investment alternatives for different assumed demand levels of both subscriber penetration (usually that percentage of households which subscribe to a service), and frequency of use, for a limited set of new services like on-demand video "juke box" service.

It is important to note that simple static comparisons of the total costs of short run alternatives 1 and 3, and longer term alternatives 2 and 4, still would not adequately address issues of the relative costs of the migration path between, for example, upgrading alternative 1 to 2 and alternative 3 to 4 respectively. In fact, depending on the specific architecture chosen for deployment of short run alternatives 1 and 3 (e.g. passive/active hybrids), it may even make sense from a relative cost standpoint to upgrade alternative 1 to 4 or 2 to 3. After all, some telephone network FTTC hybrids (e.g. Passive Optical Networks or PONs) have many features of advanced cable networks; it is often noted in recent literature that many next generation cable network architectures rather closely resemble the star networks traditionally used by telephone companies instead of the tree-and-branch cable networks they replaced. Depending on future technological devlopments, it may make sense to consider entirely new migration paths for network upgrades. In his recent book, Reed provides some qualitative and quantitative analysis of alternative network evolution paths, but admits that there is insufficient data to choose one specific network migration path over another.

### Other policy alternatives for technology adoption

There are two technology adoption paths not mentioned so far: cable/telephone company hybrid interconnected networks, and a free market, non-infrastructure approach. Both are contingent on public policies regarding how network technology adoption should occur and therefore represent potentially important influences on the other four alternatives. In the case of cable/telephone company hybrid networks, either current operating and financial restrictions must be removed altogether, or novel partnership arrangements would have to emerge under existing laws and regulations to take advantage of potential synergies between interconnected cable and telecommunication networks. As of this writing, few researchers have investigated interconnection possibilities.[30]

The free market broadband network scenario, while of interest, is not the primary focus of the present analysis which concentrates more on public policy and network infrastructure approaches. Due to the continued strong influence of political institutions and regulatory bodies, a free market technology deployment scenario is not likely, at least for the residential mass market. This is certainly the view of most informed observers. The main reason is obvious; demand lags network deployment for a very long time, and widespread deployment itself takes at least a decade. Private business investment in the US tends to be driven by relatively short term pay back/profit incentives. In a recent article, Senator Al Gore makes the point most succinctly as he describes it as a "classic "chicken and egg" dilemma".[31]

---

[30] A notable exception is some of the papers recently presented at a Columbia University conference on this topic, "Cable Industry's Future in the US Telecommunications Infrastructure," Center for Telecommunications and Information Studies, January 25, 1991.

[31] See Al Gore, "Infrastructure for the Global Village," Scientific American, September 1991, pp. 150-153. Many other foreign researchers tend to agree that only an infrastructure approach to technology adoption will result in a timely deployment from a social perspective.

Paradoxically, the near term cable network upgrade (alternative 3 above) appears to be the most readily available technical option for residential broadband, but due to tight financial conditions and free market incentives faced by owners of cable firms to maximize short-run profits, it may not be the most financially viable option. The cable industry generally has some advantages over the telephone industry. In the cable industry, capital turnover rates are higher than telephone companies, and the relative benefits in terms of new service capabilities, service quality and reliability of cable fiber optic trunk backbone networks are much greater than the potential benefits to telephone companies from similar backbone installations. Furthermore, there is nothing preventing cable firms from interconnecting their local networks to high quality high capacity telephone trunk networks to achieve "point-to-the-world" calling capability for their customers. Telephone companies do not have the reverse option of on-demand interconnection with cable firms due to cable's private non-common carrier status. Nevertheless, due partly to rate base regulation and partly to differences in capital structure, telephone companies are better positioned to finance such an upgrade.[32]

For these reasons we recommend a least cost technology adoption path utilizing interconnection to exploit the relative advantages and potential synergies of cable/telephone company cooperation to bring residential broadband network technology to fruition. Of course, this scenario raises the

---

See for example, Nicholas Garnham and Geoff Mulgan, "Broadband and the Barriers to Convergence in the European Community," Telecommunications Policy, June 1991, pp. 182-194.

[32] For a discussion of this point and comparative financial data to support it, see Egan, *supra*, Section 1, note 1, ch. 6 and 7.

specter of too much control of access to information if there is only one major broadband network provider; many have urged a common carriage requirement on the network operator to address these concerns.[33]

Simply banning outright all financial and operating arrangements, the way current rules do, prohibits telephone and cable network operators from cooperating even when it may be in their legitimate business interests to do so. The loser is the consumer that will forego, for some time at least, new service options that may arise from the synergies available from interconnected cable/telephone company networks or joint service trials. In the business case (cash flow) analysis in the next section, the NPV of residential broadband networks could be much better (albeit still negative) with joint service arrangements.

While an infrastructure approach to broadband technology adoption would advocate cooperation between cable and telephone companies for joint service provision, some researchers claim that one big dominant communications firm is even worse than the status-quo -- which almost no informed observer likes. The alternative argument in this policy debate is that the real problem for the consumer is franchising and certification rules which effectively grant exclusive rights

---

[33] Geller, *supra*, note 10 stresses this point, as does Pepper in Elton ed., *supra*, Section 1, note 5. Egan on the other hand, *supra*, Section 1, note 1, ch. 11, claims that a more important concern is the potential for market abuse from incumbent firms that enjoy effective (if not legal) local network monopolies due to regulatory franchising requirements. Removing the regulatory protection of the dominant firm is potentially a powerful disciplinary force and is likely preferred to the current combination of franchising and operating restrictions that preserve the turf of each network provider. He describes the possibility of "cooperative" competition" where dominant firms may team up to provide service, but will never be protected from competition from other large players.

to serve a given territory to telephone and cable firms. These should be eliminated. After this is done, the one dominant, but unprotected, firm is better for consumers than the current situation of two local monopolies. The competitive threat should keep market monopoly abuse from being too great,[34] and still allow for available inter-industry synergies to develop. As Geller points out however, there will still be a serious issue to contend with: how to prevent the vertically integrated ("content" and "conduit") firm from favoring their own programming or information services. Geller's preferred solution, which this author supports, is common carriage requirements, at least for the dominant local network operator.

One major reason for not simply banning cooperation between the network operator and the program or information service provider involves the cost efficiency of the transition to a residential broadband network. Most researchers agree that in the short run (10 years or so) the engineering economics dictates that some sort of hybrid network, featuring switched narrowband and distributive (passive) video delivery, is the way to go, but, as Sirbu and others have pointed out, upgrading such systems to fully switched ones is relatively expensive among long term technology adoption alternatives. Thus, the issue becomes one of the cost of transition, which is clearly minimized by encouraging interconnection and joint service provision by telephone companies, who already have a strong fiber trunk network, with cable companies, which already have broadband loops. This would allow the best (and fastest) transition path without telephone companies having to incur the cost and time of installing metallic broadband loops and passive

---

[34] While there will likely be some abuse due to dominance, it is expected to be less than with the current regulatory policy of separation and protected monopoly.

electronics only to replace them down the road with active (switched) fiber optics.

## 2.3 Network Technology Choices

Currently all of the residential access lines of cable and telephone companies are analog, as well as the telephone and television sets which use them. The reason for this is not so much the metallic subscriber access lines themselves, indeed, they may be used for digital, analog or both. The reason is the embedded base of analog equipment which uses the access line. Both cable and telephone companies have long run plans to migrate to fully digital trunk networks and access lines, but to do so requires adaptive devices and codecs to allow the embedded base of CPE to function properly during the transition phase (at least 10 to 20 years). Because today's cable and telephone networks are so different in terms of architecture and functionality, the technological transition path for each to a fully digital two-way broadband system will be significantly different. Following is a brief discussion of the technological choices associated with each of the four network upgrade alternatives.

### 1. Telephone network FTTC

This next generation network will use both analog and digital technology due to cost and demand considerations. The two main reasons for continuing use of analog technology is the relatively high initial costs of converting and switching high bandwidth video signals in the network and the strong desires of consumers and policy makers to be able to continue using existing analog receiving devices.[35] The basic functionality of FTTC systems for the residential subscriber will be high quality narrowband digital two-way voice and data services, and, for those with a coaxial cable subscriber connection, analog video service. The likely architecture will be a hybrid double star using both active (switched) and passive (non-switched) devices and components for digital voice and analog entertainment video services respectively.[36]

Once a telephone company FTTC system is in place, a subscriber can expect to be able to use, on-demand, one or two narrowband channels two-way digital services and at least one channel for one-way distributive analog video service simulataneously. A typical example for a given household might include a voice conversation, videotex access on a PC, or perhaps faxing text, while receiving a television channel of one's choice all at the same time. This would equate to guaranteed on-demand bandwidth capacity on each subscriber access line of up to 144 Kbs narrowband digital service (e.g. basic rate ISDN) and at least one 45 Mbs (6 Mhz NTSC television) broadband channel. Except for those households already owning a PC and digital phone line connection, new CPE would be required for any household desiring to use digital services. A minimum per subscriber investment of $200 is a rough estimate for an ISDN compatible full function telephone terminal and somewhat more for PC capability if one does not already own one. The potential options for advanced CPE are too numerous to mention and

---

[35] Clear evidence of this is the decision of the FCC to require that any future advanced television system (ATV) standard must accomodate the existing base of television recieving equipment or it will not be approved.

[36] For a detailed explanation of how these systems work in practice see Egan, NRRI, and Reed (cites).

there is little cost data available.

### 2. Telephone network FTTH

Over the long run telephone companies plan to migrate to fully digital fiber optic access lines all the way to the subscriber premises. Fast packet digital signalling technology will be employed and the likely local network architecture will be active double or triple star.[37] It is expected that by the time this type of network architecture can be cost effectively deployed, that the current technical problems of efficiently digitizing video production and distribution will largely be solved by the industry.

From a purely technical standpoint, the functionality of a single fiber optic subscriber access line may support all known or anticipated one and two-way broadband service applications simultaneously and in real time. Just how much peak on-demand bandwidth capacity which would be expected to "satisfy" the potential demand of a "household" is simply not known or knowable *ex-ante*. Current international and domestic broadband network standards call for basic subscriber access line rates of about 150 Mbs guaranteed signal throughput. Of course this is just a consensus estimate of network engineering experts and was not the result of any formal broadband demand analysis. Given current estimates of broadband network signal requirements, 150 Mbs would be enough to support a single households' demand for narrowband voice and data communication services up to (or even beyond) 1.5 Mbs and three high quality video channel transmissions simultaneously. It is simply not known if this is "enough" bandwidth,

---

[37] For specific examples of these see NRRI, Reed, Reed and Sirbu etc. (CITES)

especially if very high resolution full motion video telephony ultimately becomes commonplace and this must be left to further research.

### 3. Cable hybrid fiber optic/coaxial cable networks

This next generation cable network architecture might be loosely characterized as cable FTTC, however the distinction with telephone company FTTC is a significant physical difference. Current cable FTTC network designs do not bring the fiber optic trunk cable all the way out to the proverbial "curb" as telephone network designs do. The very high bandwidth designs of passive cable network architectures call for more sharing of cable facilities and electronics at the cable network fiber/coaxial cable node. While telephone company FTTC network designs usually call for only a handful of households (e.g. 4-16) to share the electronics in the fiber optic/metallic cable node, sometimes referred to as a "pedestal," cable FTTC designs often share among hundreds of households. As shown in the next section on investment costs, this allows the per subscriber network upgrade costs to be much lower for cable firms.

The most popular cable FTTC network design is probably the passive single or double star depending on how one wishes to characterize the supertrunk-to-feeder trunk connections.[38] However, the final network/subscriber connections generally utilize the same distributive bus architecture for video channel services in the same way that traditional one-way cable networks did. The cable host head end to fiber trunk/coaxial cable interface nodes constitutes one star in

---

[38] The standard industry terminology for portions of the network transmission plant including trunk, feeder, and distribution cable are somewhat different between cable and telephone companies.

this network architecture. The downstream coaxial feeder trunk cables which serve distribution area cables are more in the traditional vein of the current tree-and-branch network architecture with one important exception, the fiber optic trunk backbone allows for enough bandwidth on the coaxial cable subscriber connections to support a clear upstream narrowband voice and data communication channel.

As in the case of telephone company FTTC, this network architecture will utilize a mix of digital transmission technology for narrowband services and analog for broadband video channel services. The important distinction is that, in the case of cable, even the narrowband services are passively transmitted from the subscriber premises upstream to the cable head end. Private two-way narrowband communications is possible because the cable system is said to be two-way "addressable," through the use of head end signal processing and routing. In other words, cable companies would not do narrowband communications with switching according to phone numbers the way telephone networks do. Just as was the case with telephone companies FTTC systems, cable FTTC would require subscribers to obtain advanced converter boxes or other devices to integrate the analog telephone set with the coaxial cable drop wire. In addition, since the goal is to provide digital narrowband service, a residential customer will need a codec to convert the upstream signal. A reasonable estimate of this cost is $100 to $200 per household beyond that which a modern addressable cable converter box already costs.

### 4. Interactive broadband cable hybrid network

This long term cable architecture continues to use both fiber optic and coaxial cable for transmission and would likely be all digital but there is no imperative to be so as in the case of telephone company FTTH. Cable's long term vision is to achieve real time two-way ("interactive") broadband communications network functionality, but this does not necessarily imply a fully switched (or fully digital) system. This network alternative potentially would utilize a combination of passive and active network segments according to the specific requirements of the service being used at any point in time. For example, full motion entertainment video could be provided on a downstream digital or analog passive (distributive) video channel while narrowband voice and data services use another frequency for two-way or interactive communication service, potentially all on the same access line. There has also been much discussion recently that the cable industries long run vision may include over ther air "wireless loops" for end user narrowband services. Of course, if wireless technology progresses as rapidly as many believe it will, telephone companies also will consider its use in lieu of the fixed wireline subscriber connections.

The appeal of such a network system is that the type of transmission or service application may be flexibly accomodated by available channel capacity on a very high speed subscriber access line. In contrast, a fully switched system, while capable of supporting the same end user service demand, may do so less efficiently. Depending on the exact traffic characterisitics of a given end user service application (e.g. continuous, bursty, high speed, low speed etc.), switching all of the signals may not be the most efficient (least cost) way of operating a network system. At this early stage in network technology research, it is simply not known if such flexibility in a local telecommunication network is feasible to deploy. For example, there are already many disputes in the engineering community as to whether it will ever be cost effective to deploy a network architecture that is so flexible that it will optimize network performance in real time as the mix of end user service applications and traffic characteristics change in space and time. Such debates are common in current negotiations regarding broadband network standards in the presence of stochastic demand for services that at times are optimized for continuous transmissions (e.g. circuit switched) or are relatively bursty (e.g. packet switched), or that from time to time exhibit characteristics of both.

## 2.4 Time Frames

With a public policy imperative to help finance next generation residential broadband networks ("supply-push"), either options 1 or 3 above could definitely be achieved within a decade. This may not be enough time for ubiquitous deployment, but would be enough time such that on-demand access to a nearby fiber node for most households would be affordable; the problem of course is that there is no public policy imperative (yet). If deployment option 1 or 3 is left to the "demand-pull" of the marketplace, widely available household access to high speed fiber optic broadband networks will likely take yet another decade.

Similarly with options 2 and 4 above, widespread deployment of local interactive two-way broadband networks (the "second generation") would probably take another full decade to complete *if* a public policy imperative developed. Otherwise, left to the "demand-pull" scenario, ubiquitous residential broadband network access could be a full two decades beyond the next generation networks (alternatives 1 and 3 above). The network architecture associated with these two alternatives, featuring narrowband two-way capability and one-way broadband capability are described in more detail later.

Many authors believe that, with the rapid advances in digital signal processing techniques for "compression" of high bandwidth signals to relatively narrow bandwidth ones, the second generation broadband network is not going to be required to satisfy residential demand for the great majority of advanced telecommunication services. There are also researchers on the other side of this debate.[39] For now, this author remains eclectic, but if many of the potential demand applications identified in section 4 take off, in addition to entirely unanticipated ones, signal compression will not substantially mitigate the demand for residential broadband networks.

## 2.5 Investment and Capital Budgeting Analysis

This section presents the results of standard Net Present Value calculations to evaluate the financial viability of the short run network upgrade alternatives for both telephone and cable network companies. The computer financial model used for the following cash flow analysis is the Financial Planning Model (FPM) developed by Southwestern Bell Telephone Company. The model is a flexible and generic NPV calculator which is user-friendly and may be applied to investment project evaluation for both regulated and unregulated firms. A high level summary of FPM is attached as Appendix B. Appendix A provides a basic discussion of how to perform

---

[39] Johnson and Reed, *supra*, Section 1, note 3, and Elton in his edited volume, *supra*, Section 1, note 5, take the position that compression using advanced digital signal processing techniques will mitigate the need for residential broadband networks, while Fisher, *supra*, note 10, and Solomon (Elton ed.), *supra* Section 1 note 5, tend to take the opposite view.

cash flow analysis in practice and discusses economic principles of costing analysis.

Due to space and resource constraints for this research report, the quantitative results shown below are only illustrative of how the model may be applied using the cash flow equation and spreadsheet input data described in Appendix A. A "real world" business case application would involve many more local assumptions regarding starting point, costing methods, geography and other supply and demand conditions; this would require many more computer runs and sensitivity analyses than may be performed here. However, the numerical results are useful for evaluating the differential investment streams encountered by telephone and cable television companies for next generation residential local broadband communication networks.

It is important to note that the negative NPVs calculated in the FPM runs which were performed included cases with zero or little revenue stimulation. The basic point of this exercise is the comparison of the negative cash flows associated with the cost of technological alternatives featuring similar network functionality while holding revenue constant. Based on the discussion in Section 4 following, there are substantial potential revenue streams associated with residential broadband demand; more than enough to pay for the costs in many possible deployment scenarios. However, the demand issues are not sufficiently researched to forecast substantial new revenues with enough certainty to input them into the model at this time. The usefulness of the computer runs is to demonstrate how to conduct a business case analysis using an NPV cash flow approach and to show why such an exercise is useful even in the absence of "hard" demand data. In fact, the results do provide a straightforward quantification of the amount of additional future revenue streams (cash flow shortfalls) required to cause one to take on the project as a financially viable (stand-alone) proposition.

**Input data**

The input data required to run a NPV model is described in Appendix A. Table 2.1 below gives the basic costs used in the various computer runs actually performed for a stylized example of a 256 home suburban single family subdivision. The basic assumptions common to all three computer runs are:

1) network upgrade situation -- existing local network infrastructures (e.g. poles, conduit, ducts, support structure) for traditional coaxial cable television and twisted-pair copper telephone networks is in place and useful;

2) average residential access line length is about 10 kft., about 80% of that distance is feeder cable and 20% is distribution (of which the "drop line" is only about .1 kft);

3) to simplify the analysis and to be "forward looking," all costs are "production" costs and assume the working capacity of the system is full, therefore the costs are what would be expected in a mass deployment scenario;[40]

---

[40] Per unit costs assuming fully utilized system capacity are called "capacity costs" and its calculation is described in Appendix A. There are any number of possibilities for limited deployment and untested "prototype" architectures. However for purposes of this analysis, mass deployment in the same residential market(s) is assumed, allowing for the most convenient "apples to apples" comparisons of cable and telephone company costs. Even though such a rapid deployment is a rather heroic assumption, no assumption of demand stimulation or actual subscriber connections are made. In other words, lag times in subscriber service penetration

4) all investment and construction is assumed to occur within the first year of the study (1991) and the study period is 10 years; for modeling convenience, a mid-year convention (July) is assumed for the placement of all physical network plant;[41]

5) no CPE device and component costs are included.[42]

### Short term telephone network upgrade

A popular type of local network architecture suitable for residential FTTC systems is called Passive Optical Networks (PONs)[43] and is illustrated in Figure 2.4. The per subscriber costs for this type of system is indicated in the first part of Table 2.1 and represents a FTTC "POTS-only" system which retains the use of the original telephone drop line. However, this system is "upgradable" to broadband capability for provision of cable television and other enhanced services, including ISDN. Upgrading to broadband capability includes a coaxial cable drop

---

levels would presumably lead to delayed installations of the final subscriber connections or network electronics, etc.

[41] The NPV results can change dramatically if a phased-in or pay-as-you-go type of construction program is possible, and in fact, in actuality it would take a long time to accomplish full network conversion for large companies that serve many customers; however the potential reductions in the (already) negative NPV from a phased construction program would be expected to apply similarly for both telephone and cable television firms; for a discussion of the financial implications of pay-as-you-go construction programs see Egan, *supra*, Section 1, note 1, ch. 8.

[42] Recall, the cost of such devices would likely be similar for both types of networks (cable and telephone) since basic network functionality is similar.

[43] For a basic discussion of these vendor systems, see the recent articles: "Can PON Go Broadband," and "To Pon or Not To Pon?," Telephony, January 14, 1991, pp. 30-35 and 50-56 respectively.

installation, unless, of course, the local cable television companys' is used through some sort of cooperative arrangement. This adds about $100-200 to the per subscriber costs for aerial construction.

## Table 2.1

### TELEPHONE FTTC NETWORK COSTS

| | | Cost per Home Passed |
|---|---|---|
| **Central Office Equipment:** | | |
| Optical Transmitter, Optical Receiver | | $ 22 |
| Other Electronics | | 46 |
| Installation | | 1 |
| | **Total** | 68 |
| **Subfeeder:** | | |
| Singlemode Fiber | | 13 |
| Cable Sheath/Installation | | 113 |
| | **Total** | 126 |
| **Power:** | | |
| Power Supply | | 47 |
| **Splitter:** | | |
| Dual 1x16 Splitter | | 5 |
| Splitter Housing | | 2 |
| Splitter Installation (3 hours) | | 1 |
| | **Total** | 8 |
| **Optical Network Interface:** | | |
| Optical Transmitter, Optical Receiver | | 94 |
| Other Electronics | | 158 |
| Subscriber Line Card | | 109 |
| Installation | | 6 |
| | **Total** | 366 |
| **Distribution:** | | |
| Singlemode Fiber | | 16 |
| Cable Sheath/Installation | | 90 |
| Pedestal | | 5 |
| Copper pairs for power | | 20 |
| | **Total** | 111 |
| **Total Electronics** | | 434 |
| **Total Power** | | 66 |
| **Total Non-Electronics & Labor** | | 225 |
| **Overall Total** | | $726 |

**Assumptions:**

1.5 Lines available per Living Unit - 256 Living Units
CO Equipment assumes digital interface
8000' feeder length
Assumes ducts are in place
1580' avg. distance from splitter housing to last ONI
Network Power
The installation of the copper for power is covered in the installation of the fiber
Homes per ONI=4; Lines per ONI=8
2 fibers to each ONI
ONIs are placed in standard pedestal
Labor is calculated at $40/hr

# CABLE HYBRID LOCAL NETWORK COST

| | Cost per Home Passed |
|---|---|
| Feeder | $150 |
| Node | 40 |
| Subscriber Line Electronics | 200 |
| **Total** | $390 |

| | |
|---|---|
| Cost for telephone network interconnection: (Non-traffic sensitive monthly recurring charge for DS3 access connection between head end and CO) | $8,000/mo. |

assumptions:
60-70 subscribers per mile of trunk plant
500 subs per node
two-way amplifiers
70-80 channel capacity
average of 3-5 coax signal amplifiers in cascade on subscriber distribution cable
fiber cable cost - $.05/ft.
fiber cable aerial installation overlash - $.50/ft.
single narrowband upstream channel
subscriber electronics to support upstream narrowband channel

The additional electronics/photonics equipment costs to upgrade to broadband services is estimated to be an additional $500-600 per subscriber. Thus, the total cost of "basic" telephone company provided residential broadband local networks is estimated to be about $1,326 per subscriber (single family household).

**Short term cable network upgrade**

A current coaxial cable television local network system which provides Plain Old Cable Service (POCS) probably features 20-36 video channels and would utilize about (25-30) signal amplifiers in cascade between the cable head end and the subscriber premises. Such a system may be upgraded with a fiber-optic cable supertrunk and feeder cable backbone interconnected to the existing coaxial cable distribution and subscriber drop lines. A stylized view of this hybrid fiber-optic/coaxial cable system architecture was given in Figure 2.2. One goal of this type of system upgrade is to allow for clear upstream signaling channel(s) and for various advanced services such as Pay-Per-View (PPV), video/audio-on-demand, and video juke box services, and to increase channel capacity to upwards of 72 channels. Other advantages of cable fiber trunk networks besides increased bandwidth, include better quality, less maintenance, and greater reliability of service.[44]

The average incremental costs for a cable network upgrade capable of supporting high quality narrowband voice or data service is $150-250 per subscriber. The difference from the fiber trunk

---

[44] See Egan, *supra*, Section 1, note 1, ch. 7 for a discussion of the advantages of hybrid networks.

backbone network illustrated in Figure 2.2 is that the fiber cable is extended further downstream in the network feeder trunks to a fiber optic/coaxial cable node point capable of serveing about 200-500 subscribers, depending on the exact system which is deployed. A capacity cost[45] figure of $190 per subscriber is used in this particular study and is reflected in the cost data and assumptions listed in Table 2.1. Figure 2.5 provides an illustration of this type of cable network architecture.

A major issue for expanding the potential demand for telecommunication services on cable networks hinges on the capability for achieving high quality, two-way functionality of the network facilities to support narrowband voice, data, new multimedia services including the many potential services described in Section 4. For "basic" two-way functionality, additional costs of $200 per subscriber is the estimated production cost of electronics required to support a reliable upstream narrowband channel for two-way, point-to-point local telecommunications (i.e. within the head end service area -- addressing the called party may be accomplished at the head end).[46] Of course, it would be desirable to achieve off-local-cable-network functionality to increase the attractiveness of potential two-way services and to increase revenues. The most immediate way to accomplish this would be a telephone network interconnection link between

---

[45] Appendix A discusses the concept of capacity costs. Basically, capacity cost is the total incremental cost of a construction project divided by working capacity in units.

[46] Addressable cable television converter boxes used in conjunction with state-of-the-art hybrid cable architectures provide the capability for high quality upstream narrowband telecommunications. Some manufacturers already have production converter boxes which accommodate both telephone wire and coaxial cable connections (input and output). Thus, functional integration is possible from the converter box upstream to the cable head end.

the cable head end and the local telephone company central office switch. Some additional electronic equipment would be required at the head end to support routing and translation functions for off-net cable traffic; this cost is likely very small when put on a per subscriber basis (as are most head end costs), and in any event, is not estimated for this study. A modern "smart" converter box required on the customer premises may be expected to add $100-$200 to the up-front per household cash outlay. If the converter box costs were amortized over several years it would be quite small on a monthly basis, but this would also be the case if the telephone company broadband FTTC network were to achieve integration through some sort of set-top converter linking the household terminal devices to the coaxial cable drop. The only significant difference is that the telephone company would own and operate the one-way video distribution network.

None of the investment scenarios evaluated in this section include any assumptions of additional costs for subscriber premises equipment which may be implied by the potential range of new service offerings by either cable or telephone companies. This is reasonable in a comparative network study; presumably the terminal equipment requirements of both telephone and cable firms in the types of hybrid network arrangements considered here would be similar. The critical importance of user-friendly devices to increase demand will be discussed in Section 4.

The cost data listed above is input to FPM to assess the NPV in each of five business case scenarios:

1. investment in telephone company FTTC -- POTS only

2. investment in telephone company FTTC -- broadband network

3. investment in cable company two-way hybrid network

4. investment in cable company hybrid network with interconnection

5. investment in cable company hybrid network without interconnection

**Financial Planning Model Results:**

Scenario 1. Telephone company FTTC -- POTS ONLY

The basic input data categories for FPM is listed on page 1 and 2 of the computer output in Appendix C. This is the run for investment for telephone company FTTC POTS only; the cost data for this run is from Table 2.1. First, FPM requires the user to specify the start month and year of the study period, the number of years in the study period, and the present worth and trend base year. For all computer runs the study period begins January 1991 and lasts 10 years to the year 2000. FPM allows for a maximum of 20 different revenue streams for the study period and 20 separate expense and investment categories (including depreciable and non-depreciable investments). Each revenue, expense, and investment category is allowed to have a separate price (cost) inflation factor. Working capital and sunk investments may also be specified, but are not used here. Page 2 of Appendix C contains the input data for discount rates, tax rates, and capital structure for the given investment project. In the case of the telephone company (runs 1 and 2) the discount rate (after tax cost of money) is 12% per year, the debt ratio is 40%, and before tax cost of debt is 9% per year.

Operation, Administration and Maintenance (OA&M) expense is the only expense category used and is equal to a given percentage of the Engineering, Furnished and Installed (EF&I) cost of the total per subscriber depreciable investment. The OA&M percentages are: 15% in the start year (1991); 12% in 1992; 10% in 1993 and 9% through the year 2000, in recognition of anticipated expense declines. In this run, there are 6 depreciable investment categories which follow those presented above in Table 2.1. Each investment category has its own book and tax depreciation lives input by the user to be consistent with tax and public accounting rules. For a listing of the expense and investment input data see Appendix C (FTTC POTS ONLY) expense and depreciable investment division reports and user-defined algorithm reports.

Finally, the cash flow summary report, financial indicator summary report, and brief glossary explaining key terms are at the end of Appendix C. The cumulative discounted NPV associated with this construction project is minus $216,425.00 or $845 per subscriber. Note that this amount, calculated over a ten year study period, is only slightly higher than just the initial construction (EF&I) costs plus annual expenses for OA&M. The reason of course is that there are positive financial benefits in years 1-9 (year zero is the placement year) due to the tax effects of annual depreciation charges.

Since POTS-only functionality is assumed, no new revenues were assumed in this run. It is only for illustrative purposes to show the NPV of the construction project cost streams. However, in NPV analysis the revenue side of the picture is the mirror image of the cost side for purposes of financial break-even analysis. Thus, additional per household revenues required to fund this construction project would be $11 per month, assuming a 10% interest rate, or $12 using 12% interest over ten years.

Just as a point of interest, this run could be compared to one for traditional copper loop deployment in a given suburban subdivision (e.g. for a "new build"), in which case the technological alternative (FTTC or copper) with the least negative NPV should be chosen, which, by the way, will likely show FTTC to be the less expensive proposition over the long term in NPV terms. Egan, Reed and other researchers have identified the per subscriber costs of state of the art copper loops using digital loop carrier concentration technology to be about $1,000. It must be kept in mind however that in a new build situation, additional costs for network support structures would have to be added to the FTTC costs since for purposes of this computer run, these structures were assumed to be already in place. On the other hand, the revenue potential for narrowband systems, regardless of what it actually is, would be expected to be potentially greater for FTTC *vis-a-vis* the all copper loop.

### Scenario 2. FTTC -- Broadband

In this run, the cost of the FTTC system in scenario 1 is increased by $600 per subscriber to provide broadband capability; approximately $100 for a coaxial cable drop line and $500 for additional electronics equipment. The total cost is now $1,326 per subscriber. The computer output for this run is Appendix D. Note that only changes in the data used in scenario 1 are required to be input to the model: increased investments and attendant OA&M costs, and a single new revenue category. Monthly revenues are assumed to increase: $1 per household in 1991; $2 in 1992; $4 in 1993; and $8 for 1994-2000. These are likely very conservative since basic one-way cable service costs about $14 per month per subscriber, and construction and service capability is assumed in the first year (1991). Even new one-way digital audio service being offered by some cable television companies costs subscribers about $10 per month.

The NPV is now minus $346,648 or $1,354 per household. This represents the NPV amount of new revenues required from this project to make it a viable stand-alone business proposition at a 12% cost of capital, or, in a rate base ROR regulated environment, the additional total revenue requirements spread over all ratepayers. The revenues required to finance this project would therefore be $19 per month per household over ten years.

### Scenario 3: Cable Hybrid Network with Telephone Network Interconnection

This is a cable network broadband scenario for the same prototypical subdivision which was assumed earlier. Appendix E contains the computer output of FPM for this scenario. The format of the output report is exactly the same as those presented in the first two telephone company scenarios. Notice on page 2 of Appendix E that the discount rate assumed for this run is 17% instead of 12% for the telephone company runs; the debt ratio is 80% and before tax cost of debt is assumed to be 12%. Tax rates are assumed to be similar to those for telephone companies. Of course, local tax rates likely vary among municipalities. Some different depreciation assumptions were made for cable, but accelerated depreciation was assumed as in the telephone company runs.

The depreciation assumptions for each category of depreciable investment are spelled out in the computer output in each of the Appendices in the Depreciable Investment Division Report sections. In this run, no additional revenues are assumed so that a comparison with the telephone company FTTC POTS- only run may be made. In other words, even though the added functionality available on the hybrid cable network is greater than telephone company FTTC for POTS only, this run simply shows the NPV of the cost streams associated with the construction project.

The network cost data input is from Table 2.1; $390 is the per subscriber EF&I cost and the OA&M expense is assumed to be 10% of EF&I costs for all years in the study. Also included is the cost of a DS3 (45Mbs) link, a dedicated two-way fiber optic communication channel connecting the cable head end and the telephone central switching office location which serves the same subdivision, leased by the cable company at fixed tariff rates of $8000/month for this specific access arrangement. Notice the resulting NPV of minus $760,515 or $2,971 per household (Appendix E Financial Indicators Executive Summary, page 1 of 5). This translates into per subscriber monthly revenues of $52, much higher than the telephone company runs; the last computer run, that does not include the very expensive charges for telephone network interconnection reveals why.

Scenario 4: Cable Broadband with Telephone Interconnection

This is the same as Cable Scenario 3 except the same (small) increase in new revenue streams is assumed as in Telephone Company Broadband Scenario 2. The NPV is minus $635,975 or $2,484 per subscriber. The monthly revenues required to finance this project are $43 per subscriber. The computer output is displayed in Appendix F.

Scenario 5: Cable Broadband without Telephone Network Interconnection

The computer output for this scenario is in Appendix G. To show the significance of the recurring monthly tariff rate for telephone network interconnection, this run is the same as Cable Scenario 4 except that no interconnection with the public switched telephone network is assumed, saving $96,000 per year. Notice that this alone brings the NPV to minus $11,975 or only $47 per household. At 17% interest the monthly additional per subscriber revenues required to finance the project would be only $.81.

This run shows that, even with modest assumptions of increased revenues and assuming all construction costs are incurred up front (NPV study year 0), cable provided residential broadband networks are very close to passing a NPV test for stand-alone financial viability in a network upgrade situation. The key cable network cost problem is telephone network interconnection, and this must become a priority for cutting costs through some sort of bypass arrangement or perhaps a cable owned private line special interconnect arrangement. Market prices for private interconnect arrangements are much lower than current telephone company DS3 fiber rates.

Perhaps future regulations requiring telephone companies to provide Open Network Architecture (ONA) would allow for cheap interconnection of cable-owned transmission facilities at the telephone network switch, in which case the regulated tariffs for basic interconnection services would be "unbundled." This would allow for cable firms to pay monthly charges only for telephone company multiplexing and switching, not for the leased line itself. Without such an arrangement, cable companies must hope to generate sufficient new revenues from on-network local two-way traffic, or will need alternative possibilities for intercity transmissions, such as cellular radio, Personal Communication Networks, or Alternative Access Providers (AAPs) like Metropolitan Fiber Systems (MFS) and Teleport Communications or others using microwave radio, satellite and/or fiber-optic technologies.

## 2.6 Comparison of results with existing literature

There have been a handful of studies which estimated the per subscriber cost of network upgrades for residential broadband networks, however, each has their unique assumptions regarding initial and on-going supply and demand conditions. The types of network upgrades which are perhaps most comparable to the next generation telephone and cable networks used in this study are those by Reed, Johnson and Reed, and Reed and Sirbu cited previously. Each of these studies estimated per subscriber network upgrade costs for a variety of alternative network architectures and demand conditions. From these studies there are a few cost estimates that could be compared to the limited cases examined herein, that of a network upgrade from traditional telephone service to a POTS network that also provides basic distributive video channel services or, in the case of cable, an upgrade of a basic POCS network to provide two-way narrowband telephone services.

In his book, Reed estimates the per subscriber costs of a POTS network upgrade for distributive video services to be $1,242 for a passive hybrid double star using both analog and digital technology for video and voice and data services respectively.[47] This is very close to the vendor cost in Table 2.1 of $1,326. Johnson and Reed estimate the per susbcriber cost of a POTS network upgrade to provide on-demand video services at about $1,600. Their per subscriber cost estimates rise as per household television viewing hours increase.[48] In the Reed and Sirbu study, which pre-dates the others, the cost of a residential broadband network capable of supporting POTS and distributive video service is estimated to be $1,700 per home passed for a passive double star hybrid network architecture.[49]

What is perhaps striking about all of the studies is how closely the numbers compare in the

---

[47] Actually, Reed's per household cost estimates are for "homes passed," rather than subscribers. However under the rather heroic assumptions made herein regarding mass deployment and full system utilization, "per home passed" becomes roughly equivalent to "per subscriber." See Reed, *supra* note ___, Table 5-3.

[48] See Johnson and Reed, *supra* note __, Table 3.

[49] See Reed and Sirbu, in Martin ed., *supra* note __, Table 5-1.

presence of some very different assumptions regarding supply and demand conditions, which are too numerous to mention. The methods used in previous studies to calulate the per subscriber investment results were also different from those used here and yet the cost estimates are similar. This is encouraging and indicates that the cost estimates for next generation residential broadband networks are robust. An informed observer would perhaps have anticipated that the results would be similar for two main reasons. First, all studies are necessarily based on cost data for network equipment from vendors using a very homogeneous physical technology. Even though there are any number of physical network architecture designs available from vendors of hybrid broadband networks, they all are using the same types of physical devices and components. For example the costs of fiber optic cable and lasers are the same for all vendor systems. Furthermore, network system vendors are in a very competitive business and therefore they would tend only to pursue those architectures which are cost competitive with other vendors of next generation network equipment. No vendor of basic network systems can afford to have much higher system costs than another. Installation costs for major items like laying fiber optic cable represent a large portion of total costs and these are approximately the same for all vendors of residential access lines.

Secondly, various cost estimates should be similar because the standard net present value calculations for the investments are fundamentally the same regardless of the computer program used. One would also expect that all authors use the similar basic financial assumptions of tax, interest and depreciation rates since they have been well established in the industry.

## 2.7 Implications of current network upgrade strategies for long term vision

The long transition path from today's public telecommunications network infrastructure to an advanced broadband infrastructure featuring a fully switched digital fiber optic network raises some important issues concerning the total cost of achieving it. When the advancement of fundamental network technology is rapidly changing it is not going to be possible in practice to minmize the total social cost of technology adoption due to the long lived nature of the investments that are made in the short to medium terms of the transition phase. The economics of technology adoption, especially in a market driven environment, is partly a process of discovery, fixing one big optimal plan will not be possible. Nevertheless, it is incumbent on the research community to try to identify those steps in the process that may represent socially efficient expenditures. In theory, if one were starting from scratch with what economists call a "scorched earth," there is a dollar investment amount that represents the *total incremental cost* of deploying a broadband communication network infrastructure based on a least cost long run network optimization model. Since we are not starting from scratch there is also a theoretical expenditure to upgrade the existing infrastructure to a fully switched digital one again based on the total incremental upgrade cost of the least cost network design.

In practice, many short run market driven strategies for network upgrades will not be consistent with the social long term optimum network and therefore the total cost will exceed, perhaps considerably, the total incremental cost referred to above. What short term startegies fall into this category? The most popular next generation network vendor systems utilize passive delivery of video communications in FTTC local network architectures; based on the detailed work of

Reed and others, it is clear that the use of passive delivery of video signals in hybrid broadband networks will increase the total cost of ultimately deploying a fully switched system. There are many reasons for this, not the least of which is the inertia inherent in existing video technology utilized by current networks and CPE. Deployment of such network systems may raise substantially the total cost of achieving an advanced two-way broadband network infrastructure. This could only be avoided by significant rapid advances in switched network system designs which are not currently cost competitive with passive systems for the provision of distributive video service like cable television. Unfortunately this is not likely.

Reed and others have shown that there is little to be gained in terms of engineering economies by combining distributive video service delivery with two-way switched telecommunications on a single fiber optic or coaxial cable access line. If it is true that the economies of scope from integration of these two services is very small, deployment of such networks will not be justifiable on the basis of engineering cost savings alone. So why do telephone companies still pursue this short term strategy? The reason is twofold. First, even though the preferred long term vision is a fully switched integrated broadband system, the market for narrowband services is a very sluggish one. Everyone who wants a phone has one, and annual growth rates for per household telephone usage are only slightly higher than population growth rates. On the other hand, video services and new digital data exhibits high growth rates and forecasts continue to be very optimistic. If a telephone company is going to be a player in the high speed data and video services market, they cannot wait for the "right" technology to come along that is best suited for achieving the long term vision. They must move soon or risk losing their dominant position in the marketplace. Thus even though there may not be much to gain in terms of network cost savings by integrating passive delivery of downstream video services with the telephone network, it at least represents a step in the direction of network integration which has become something of a holy grail of telecommunications network engineers. Secondly, the only alternative to network integration is to continue the status quo of separate services (e.g. voice, data, video) provided on separate access lines. To telephone company management this is not a very exciting proposition, and would force them to continue to serve the less than glamerous basic telephone service markets. Furthermore, without integration with the public switched telephone network regulators would not allow telephone companies to invest proceeds of the telephone business in other closely related lines of businesses like cable television. Besides, it is probably true that in the very long run the demand for real time two-way multimedia telecommunications will grow substantially and it is worth the cost to begin the network integration process now.

Thus FTTC systems will likely be widely deployed by telephone companies. What is perhaps most disconcerting about this for the long term is that not only will passive video delivery be employed, but that it calls for deployment of "plain old coax" for the subscriber line connection. Of course there already is a coax line for cable television now, and if the long term vision calls for FTTH systems, is it socially efficient to deploy FTTC for the next generation of resdiential local networks? In the case of the shared fiber trunk network, cost savings alone will justify rapid deployment of fiber optics and it is consistent with the long term vision, but this is not the case for the coaxial cable access lines.

Regulators are caught in the middle of all of this. They would like to see a strong and progressive telephone company network, but the costs of the network upgrades, even for FTTC, are substantial. If they allow it to go into the regulated rate base, subscriber rates would have to rise because as stated previsouly, there are no cost savings on the subscriber access lines. Public policy in the US aggravates this situation further. By denying telephone companies free entry into markets for information and video services and manufacturing there is no significant opportunity to expand the revenue base from the sale of new services to pay for the investment in the network upgrade.

If all of this known, why do the FTTC network system vendors use passive video delivery and coaxial cable access lines? The reason is again twofold, one is market driven and one driven by misguided regulatory policies. Network system vendors are in a very competitive market and only sell to a handful of customers with very homogeneous needs, primarily the local telephone companies. The network technology itself is homogeneous and standardized to meet the basic requirements of the public telephone network. Thus, the cost competitive network systems should be similar in their basic design, and it turns out that they are.

Furthermore, it is no coincidence that all of the competitive network FTTC systems have per subscriber costs which are actually lower than the current marginal cost estimates of new copper access lines, about $1,000 each. Regulation in the industry has forced this result. In their reticence to approve telephone company network upgrade plans, regulators have given a silent message to the local telephone companies: if you want to deploy FTTC hybrid networks, they better be cheaper than new copper phone lines or we will not accept the bill for them on behalf of the basic ratepayers. This is why every major LEC has announced that they will cost justify FTTC systems on the basis of POTS service alone or they will not engage in widespread deployment. In addition to putting off a fight with the regulators, this strategy also avoids raising the political hackles of various other interest groups like print publishing and cable television who argue that LEC deployment of broadband networks is an unnecessary expense for society and is really just a plan to cross-subsidize entry into "competitive" markets, which they currently dominate. Even though this telephone company strategy is politically accomodating, it still may result in a very slow technology adoption process. The reason is that the new FTTC systems are cost effective for situations where new or replacment subscriber lines are needed, not for changing out existing copper lines. Thus, based on cost savings alone, at the rate which new and replacement suubscriber lines are needed, only (2-4%) per year, it would be very long indeed before the existing base of copper lines is retired in favor of fiber optic systems.

One obvious partial solution to some of these problems is to allow the telephone and cable compaies to cooperate to provide new broadband telecommunication services, but this is against the law. LECs are not allowed to have any financial interest in the cable business and therefore they would not be allowed to share the risk of such investment projects. There are few benevolent cable operators who would like to engage in physical joint service provision with a LEC when all of the financial risk is on the cable firm.

The bottom line is that the institutional and political environment itself is largely responsible for what we observe in terms of sub-optimal network technology adoption and this raises the total cost of achieving the long term vision, if it is to be ultimately achieved at all.

Where is cable in all of this? Are they on an efficient network upgrade transition path? The answer probably is that they also are not likely to be acting efficiently. First, their incentive to adopt new technology is not strong due to the lack of any effective competition in their basic video business. Second, they also have problems with telecommunications regulators and policymakers. If they begin deployment of two-way switched network capability, they will potentially become subject to the strict laws and regulations faced by telephone companies, including a cap on their monopoly profits. Having stated this however, the risk of not recovering the costs of network upgrades is not nearly so bad for cable firms as it is for LECs. The reason is that they already have incurred the very high costs of deployment of broadband capable access lines. The cost of the fiber trunk network installation in the hybrid network systems will pay for itself in terms of cost savings over time, and, in any event, it is not a significant cost on a per subscriber basis.

Cable knows that their monopoly cannot last forever and they are gaining more incentive to adopt new technology so that they may be a stong player in the broadband and multimedia service market of the future. In a sense, they must begin to aggressively pursue technology adoption as a sort of telephone company "repellant." In fact, it was not until all the hype about the potential of future broadband telephone networks to provide video services that the cable industry decided to fund the creation of the Cable Labs center for research and development.

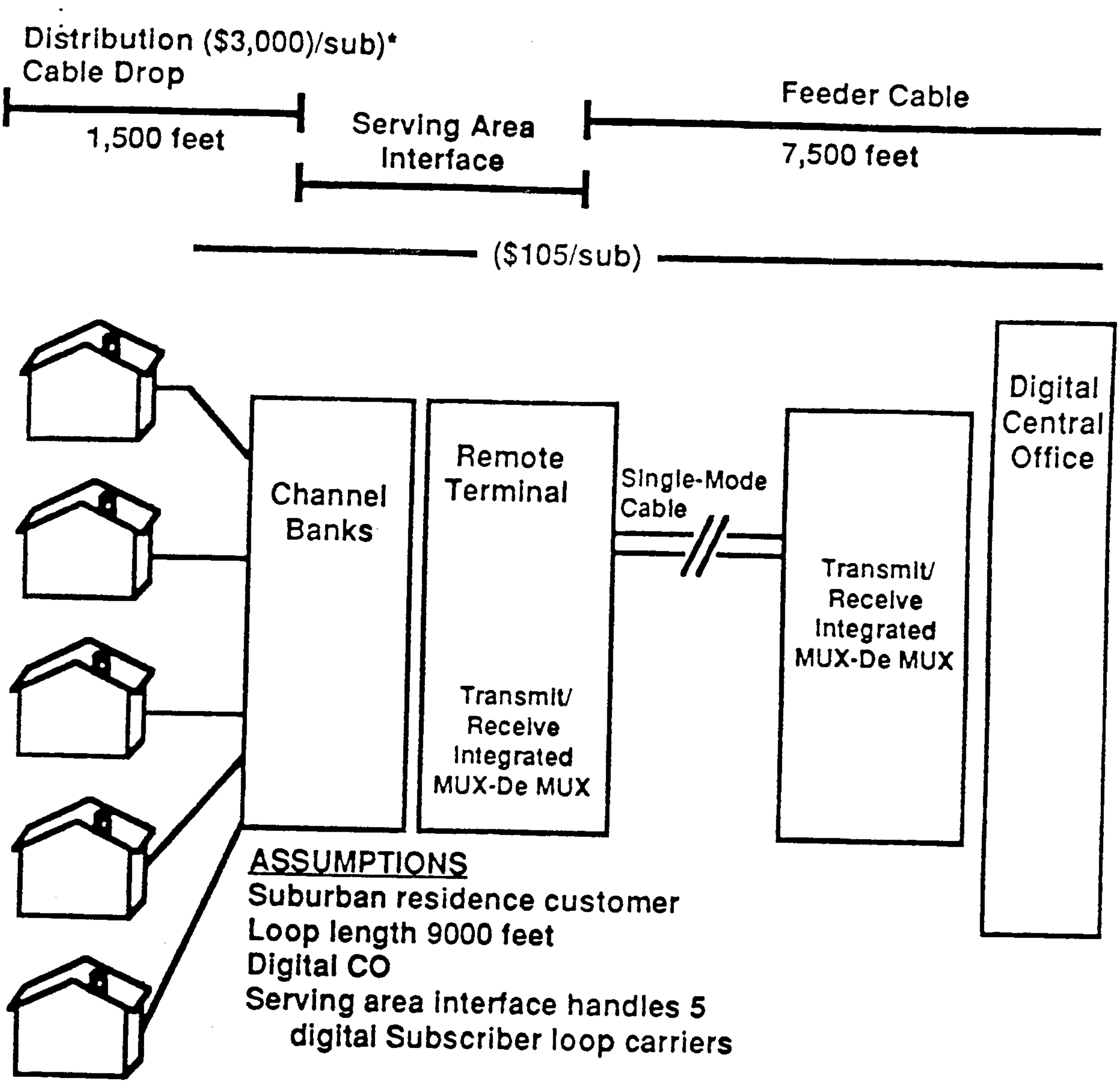
Local telephone company lobbyists often point to the lack of new technology and two-way services as the reason that they should be allowed to provide some competition for the cable industry. This has caused cable to do something about this and their interest in fiber optics and digital technology is by now substantial and will continue to grow.

Again however, outdated regulations will continue to take their toll on network technology deployment. Cable is still very concerned about being designated a telephone common carrier if it begins providing two-way voice and data services. Common carriage regulation puts at risk their very lucrative programming and production business. As it now stands, a cable system operator is free to choose what programs and channel assignments it wants and of course the incentive is to favor ones own programming. Thus the imperative to move toward a fully switched digital system is harmed and, as in the case of telephone companies, this may cause cable to make some socially sub-optimal investment decisions for network upgrades.

In conclusion, we are moving to a long term vision of a fully switched digital broadband network infrastructure, but with sub-optimum short and medium term investments in network upgrades. Unfortunately, it is not just the pressure of the private marketplace which emphasizes short run profits and market share that is causing the sub-optimal investments for the long term, it is also largely the result of outdated and misguided laws and regulations that are designed more to protect competitors and their turf rather than to protect consumers. The desires of consumers are clear, they want more service options at the lowest possible cost. The way to achieve this is competition and the incentives it creates to adopt advanced and least cost network technologies. Market processes are dynamic and full of risk and uncertainty and are therefore a process of discovery. No doubt sub-optimal network investment decisions are natural in the short and medium terms, but is not good to aggravate the situation with public policies that provide the wrong investment incentives for network operators.

Figure 2.1 FTTH POTS

Cost of Fiber POTS

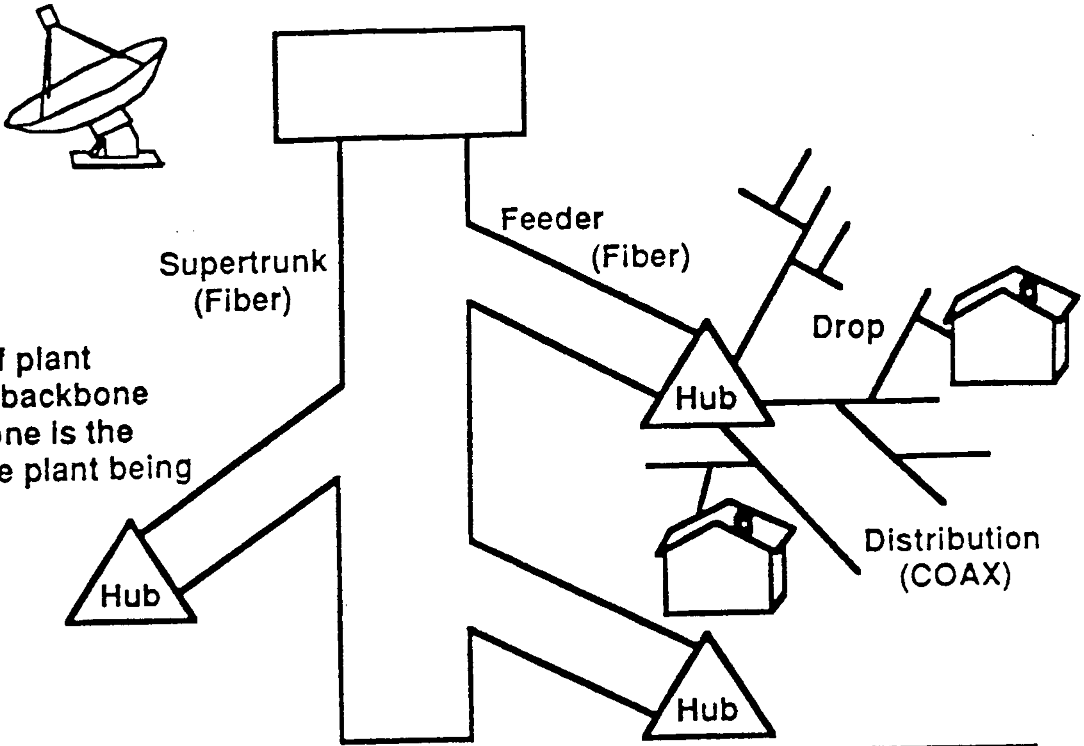


<u>ASSUMPTIONS</u>
Suburban residence customer
Loop length 9000 feet
Digital CO
Serving area interface handles 5
digital Subscriber loop carriers

* Of the $3,000/sub $900 = electronics
$2,100 = fiber link

# Figure 2.2 Cable Fiber Back Bone Trunk

## Hybrid COAX/Fiber System*



ASSUMPTIONS
10,000 Subs
375 total miles of plant
51 miles of fiber backbone
The fiber backbone is the only part of the plant being replaced

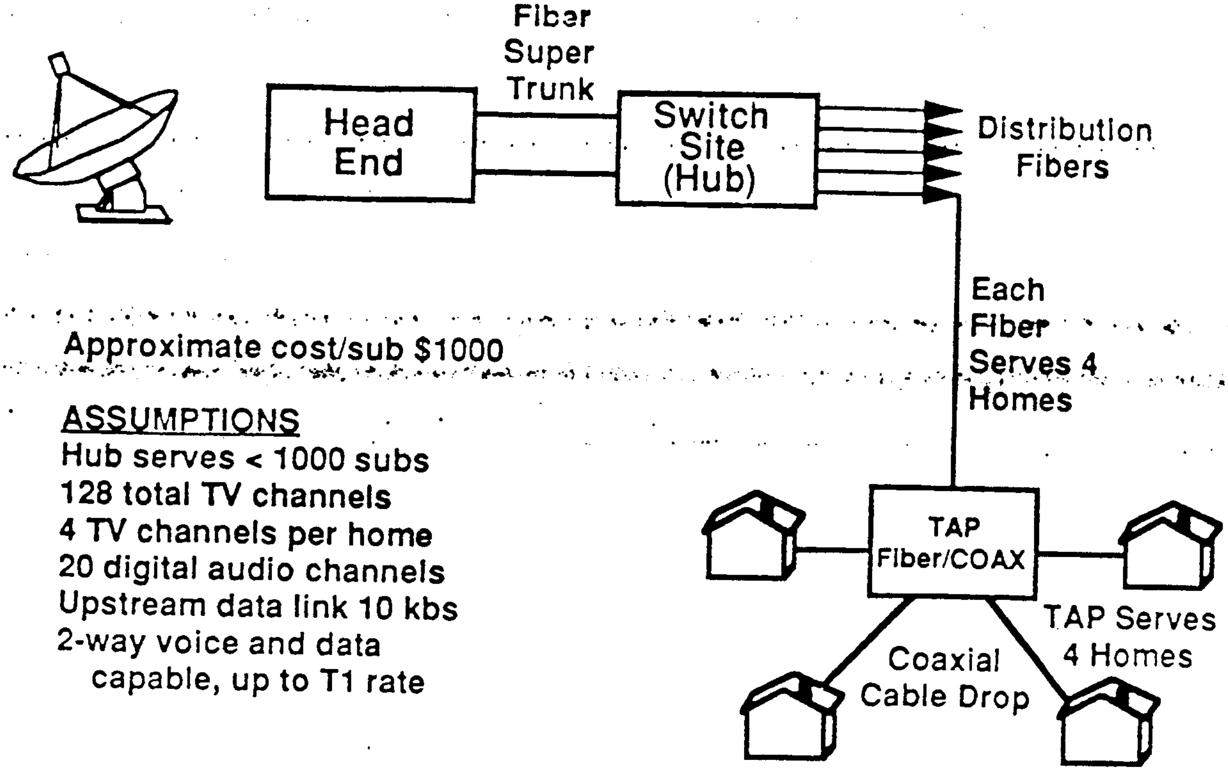
| Cost (per Sub): | |
|---|---|
| Electronics | $17.9 |
| Fiber Trunk | 18.1 |
| Total | $36 |

| Percent of total cost | |
|---|---|
| Electronics | 49.6% |
| Fiber Trunk | 50.3% |

* Based on ATC

# Figure 2.3

## Jerrold Labs "System K"

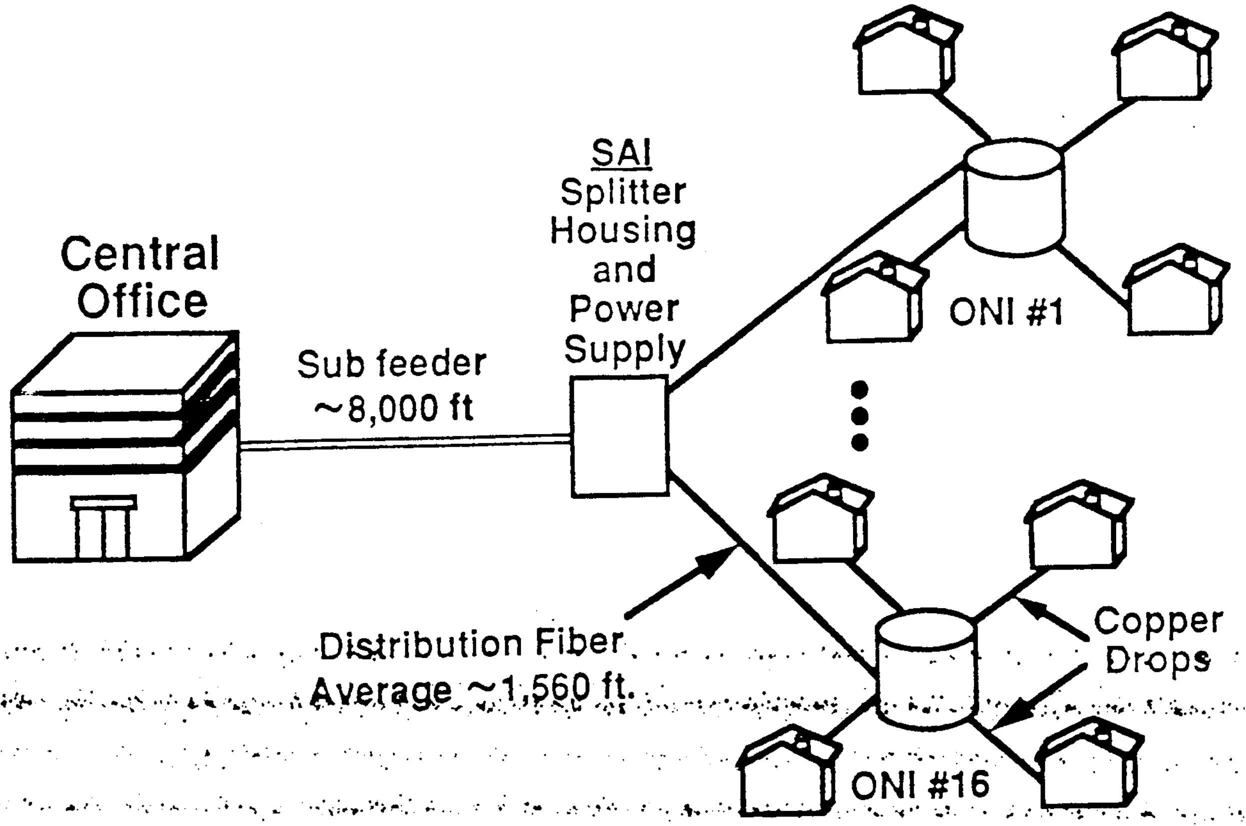


Approximate cost/sub $1000

ASSUMPTIONS
Hub serves < 1000 subs
128 total TV channels
4 TV channels per home
20 digital audio channels
Upstream data link 10 kbs
2-way voice and data
capable, up to T1 rate

# Figure 2.4

## Passive Optical Network (PON)



# Figure 2.5 Cable Feeder Net Upgrade